Elec.—Vol. III. Frontispiece

THE USE OF THE HOLTZ ELECTRICAL MACHINE IN ELECTRO-THERAPEUTICS

ELECTRICITY IN EVERY-DAY LIFE

IN THREE VOLUMES

BY

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CONTENTS

CHAPTER XXIX

CHAPTER XXX

VI—ELECTRO-THERAPEUTICS

CHAPTER XXXI

CHAPTER XXXII

CHAPTER XXXIII

FULL-PAGE ILLUSTRATIONS

VOLUME THREE

IN COLOR

IN BLACK AND WHITE

LIST OF ILLUSTRATIONS

ELECTRICITY IN EVERY-DAY LIFE

(VOL. III)

THIRD PART

THE ELECTRIC ARTS AND SCIENCES

(CONTINUED)

"*Art and science are not cast in a mold, but are formed and perfected by degrees.*"

—MONTAIGNE

INTRODUCTION

THE wide scope of the electric arts and sciences will be recognized from the fact that, notwithstanding the comparatively condensed manner in which they have necessarily been treated, there is, nevertheless, required for their proper elucidation, two volumes, or two-thirds of the space allotted to the entire book. **Wide scope of the electric arts and sciences.**

While for some reasons it might have been better to treat the electric sciences, viz. Electro-Chemistry, Electro-Therapeutics, and Electric Measuring Instruments, by themselves after the treatment of the electric arts, yet the course taken in the preceding and following chapters has been preferably followed by the author, because, in his judgment, the entire subject can, in this manner, be better understood by the class for which these books have been prepared. **Reasons for combining the two.**

I

ELECTRO-CHEMISTRY

CHAPTER I

SOME EARLY INVESTIGATIONS IN ELECTRO-CHEMISTRY

"Davy's discovery of the compound nature of the alkalies attracted universal attention, and chemists throughout Europe were occupied with a repetition of his experiments, and an examination of the remarkable properties of the singular metals which can thus be obtained. So singular indeed are these properties, that many chemists denied to these substances the name of metal, and by some they were considered to be compounds of hydrogen, this view being apparently borne out by the evolution of hydrogen when these metals are thrown into water. A more accurate examination, however, of the properties of these substances proved them to be of a truly metallic nature."—*Chemistry:* ROSCOE and SCHORLEMMER

ELECTRO-CHEMISTRY is that branch of electric science which treats of electric combinations and decompositions effected by the electric current. It treats of the combination of the so-called ultimate atoms of matter to form molecules, and the decomposition of molecules by the agency of the electric current. **Electro-chemistry defined.**

The science of electro-chemistry may be said to have had its origin during the early decades of the Nineteenth Century—during the years of 1830 and 1831—in the investigations of Nicholson and Carlisle, Davy, and Faraday. Like many other branches of electric science, electro-chemistry has not, until quite recently, been applied to any extended commercial purposes, but has found its **Origin of electro-chemistry.**

principal use either in the laboratory of research or on the lecture platform. With the advent of cheap electric current, that accompanied the utilization of such water powers as Niagara, numerous applications of the science have been made; so that electro-chemical technology has now become a well-recognized art. As example of this, witness the numerous chemical manufactories which have recently sprung up in the neighborhood of Niagara Falls.

Late date of positive knowledge of electro-chemical phenomena

Wonderful as are the effects produced by electricity and magnetism in the various fields we have already discussed, there yet remain to be described more wonderful effects in the domain of electro-chemistry. Here we deal more directly with the minute particles, or atoms, of matter, and study the formation or decomposition of molecules under the influence of the electric force. Here we see wonderful groups of new properties spring into existence as new molecules are built up under electric forces, or as the old molecules are electrically torn apart. Many of these changes are so marvellous that they could not have escaped the attention of early investigators. We would, therefore, naturally suppose that this branch of electric science would have been the earliest in which much positive knowledge was gained. This, however, does not appear to have been the case. Although many of the more striking phenomena were noticed at very early dates, yet it was not until at much later times that the electric nature or direct cause of many of these changes was certainly known.

The alchemist in his tireless research for the philosopher's stone that would change the baser metals into gold, necessarily obtained, although in a hap-

hazard way, a fairly extensive knowledge of some of the general properties of the metals. In his efforts at transmutation, he subjected all the metals that he could find to the action of various chemicals or to great heat for the purpose of obtaining them in a state of solution. In this manner, various chemical and physical processes were performed on the metals, in some of which, beyond reasonable doubt, he could hardly escape obtaining electric effects. In practically all cases having obtained some metal in the form of a solution, he performed one physical process or another on the solution which caused it to deposit the metal in a solid, and, as he hoped, in a new form. Some of these precipitations, as we now know, were of an electro-chemical nature, but this fact apparently entirely escaped him, as, indeed, they escaped the attention of the many bright scientific men who afterward rediscovered them.

Alchemy unwittingly employs electro-chemical processes.

Electro-chemical precipitations.

As an example of the fact above referred to, take the case of the well-known effect produced when a bar of iron is immersed in a solution of copper sulphate. Under these circumstances, voltaic couples are formed, consisting of the iron and some impurity, such as carbon, invariably found in commercial iron. It is the electric current, which is so produced by these minute voltaic cells, that decomposes the copper solution and causes metallic copper to be deposited in a thin layer on the surface of the iron. Robert Boyle, a contemporary of Otto Guericke, a man celebrated for his chemical and physical knowledge, in a book entitled "The Mechanical Causes of Chemical Precipitation," published in 1675, speaks of such results as being well known during his time. Boyle, referring to the different ways in which a dissolved solid may be again made to assume the solid state, says:

Boyle on the mechanical causes of chemical precipitations.

"Another way whereby the dissolving particles of a menstruum may be rendered unfit to sustain the dissolved body, is to present them another that they can more easily work on.

Boyle on refiners' method of recovering silver from solutions.

"A notable experiment of this you have in the common practice of refiners, who, to recover the silver out of lace and other such mixtures wherein it abounds, use to dissolve it in *Aqua fortis,* and then in the solution leave copper plates for a whole night (or many hours). But if you have a mind to see the experiment without waiting so long, you may imploy the way, whereby I have often quickly dispatched it. As soon, then, as I have dissolved a convenient quantity, which needs not be a great one, of silver in cleansed *Aqua fortis,* I add twenty or twenty-five times as much of either distilled water or rain water; (for though common water will sometimes do well, yet it seldom does so well;) and then into the clear solution I hang by a string a clean piece of copper, which will be presently covered with little shining plates almost like scales of fish, which one may easily shake off and make room for more. And this may illustrate what we formerly mentioned about the subsiding of metalline corpuscles, when they convene in liquors wherein, whilst they were dispersed in very minute parts, they swam freely. For in this operation the little scales of silver seemed to be purely metalline, and there is no saline precipitant, as salt of tartar or of urine, imployed to make them subside. Upon the same ground, gold and silver, dissolved in their proper menstruums, may be precipitated with running mercury; and if a Solution of blew vitriol (such as the Roman, East Indian, or other of the like colours) be made in water, a clean plate of steel or iron being immersed in it, will presently be overlaid with a very thin case of copper, which, after a while, will grow thicker; but does not

Precipitation of copper on immersed iron.

adhere to the iron so loosely as to be shaken off, as the precipitated silver newly mentioned may be from the copper-plates whereto it adheres. And that in these operations the saline particles may really quit the dissolved body, and work upon the precipitant, may appear by the lately mentioned practice of *Refiners,* where the *Aqua fortis,* that forsakes the particles of the silver, falls a working upon the copper-plates imployed about the precipitation, and dissolves so much of them as to acquire the greenish blew color of a good solution of that metal. And the copper we can easily again without salts obtain by precipitation out of that liquor with iron, and that too, remaining dissolved in its place, we can precipitate with the tasteless powder of another mineral."

Boyle's lost opportunity.

It is curious how near one can sometimes come to making a great discovery, as Boyle did in this case, and yet entirely pass it by. Boyle was regarding these phenomena entirely from the standpoint of a chemist, and was, therefore, satisfied with the explanation that the silver left the aqua fortis, or nitric acid, as we call it to-day, to unite with the copper, on which, as he says in the first paragraph of the above quotation, it could more readily work.

The alleged partial transmutation of iron into copper and silver into gold.

Just how long before the time of Boyle such phenomena were generally known, it is impossible to say. There would seem, however, to be but little doubt, that very long before this time, many of the alchemists employed similar processes in their endeavors to change the baser metals into gold. Indeed, in some old works on the subject, we are told that certain well-known alchemists had actually succeeded in transmuting a bar of iron into a bar of copper by merely dipping it into a liquor obtained

from an old copper mine. Only, as the narrative naïvely goes on to state, this transmutation was not complete, and only affected the surface of the iron. As we know to-day, there had occurred an electro-chemical deposit by the mere act of dipping the iron into the copper solution. Other statements, from similar sources, lead us to believe that, in a similar manner, gold had been deposited upon the surface of silver or copper, and that dishonest alchemists had employed this process for the purpose of misleading the credulous.

An electro-chemical deposit.

In addition to the above references as to early phenomena in electro-chemistry, there are a number of well-known experiments in chemistry that are based on electro-chemical decompositions. One of these, called the experiment of the lead tree, may be readily tried as follows: Dissolve in water a small quantity of sugar of lead or acetate of lead. This is a poisonous substance, and should not be left where ignorant people may injure themselves with it. Place the solution in a clear glass jar and suspend in it a piece of clean sheet zinc, by means of a thread, so that it will be surrounded on all sides by the solution. In a short time a deposit of metallic lead, in the shape of bright, shining scales, will appear on the surface of the zinc. These shining particles so cling to the surface of the zinc plate and to one another, that the shapes assumed are not unlike the branches and leaves on the tree. Hence the name of the experiment. In a similar manner other metals, such as silver and tin, can be deposited in tree-like forms from their solutions, by the action of weak electric currents.

Lead tree.

But in addition to the above phenomena, there were other evidences of electro-chemical action tak-

ing place, not on the limited scale with which such experiments are carried on in the laboratory, but on the larger scale on which nature operates. A Frenchman, named Becquerel, showed that metals and their ores have, in, perhaps, the great majority of cases, been deposited in veins in the rocks by the long-continued action of weak electric currents on the solution of metals that highly heated waters have brought up from considerable depths. Becquerel succeeded, on a minute scale in the laboratory, in carrying on what nature was doing on so grand a scale in the rocks of the earth's crust. In one experiment, he partly filled a glass tube with a solution of nitrate of copper, then throwing a few crystals of copper oxide to the bottom of the vessel, he placed a small plate of copper in the solution, and hermetically sealed the tube. At the end of a few days beautiful red crystals of copper oxide were formed by the action of the weak electric current produced through the mutual action of the substances in the tube. In a similar manner Mr. Crosse, of England, formed beautiful transparent crystals of carbonate of lime on the surface of a piece of slate immersed in spring water. He wound a platinum wire, connected with the negative terminal of a small voltaic cell, around the slate, and then placed near it, in the water, a mass of magnesian limestone, around which was wrapped a second platinum wire connected with the positive terminal of the cell. After a long time, the prolonged action of the current caused crystals to form on the surface of the slate.

Electro-chemical origin of metalliferous veins.

Becquerel on the origin of metalliferous veins.

Artificially formed crystals of copper oxide.

Crosse's experiment

In 1762, Sulzer, to whom we have already referred in connection with the voltaic cell, observed that a peculiar sensation was produced when plates of silver and lead were placed respectively above and below the tongue with their ends in contact. He

Sulzer.

does not appear, however, to have referred this fact to its true cause—the production of an electric current; and he, too, lost the opportunity of making a great discovery.

Passing now from these earlier and unrecognized effects of electro-chemistry, we come to the consideration of phenomena that were correctly regarded as of electro-chemical origin.

Decomposition of water by Leyden-jar discharges.

The power possessed by an electric discharge from the ordinary frictional electric machine to produce electric decomposition was known before the invention of the voltaic pile. Leaving out of consideration such chemical phenomena as the ignition of gases by the passage of an electric spark, or the oxidation of metallic substances during their electric deflagration, which were effects merely produced by increase of temperature, we find that, as early as 1790, Paetz, Van Troostwick, and Deiman discovered that the Leyden-jar discharge was capable of decomposing water. In this experiment, the discharge was passed through the water by means of fine gold wires. Very powerful discharges were necessary, and the small quantities of constituent gas collected showed that the amount of decomposition had been very limited.

In 1801, Dr. Wollaston, a short time after the invention of the voltaic pile, so modified the above experiment of Paetz, Van Troostwick, and Deiman, that he was able to decompose water by means of electric discharges from ordinary frictional machines without the aid of Leyden jars. Wollaston accomplished this by sealing the gold wires, that led the current into and out of the water, in capillary glass tubes, only leaving the ends of the wires exposed. In this

POWER AT NIAGARA FALLS FOR ELECTRO-CHEMICAL INDUSTRIES

One of the Niagara power houses, that of the Hydraulic Power and Manufacturing Company, at the water's edge, in the gorge below the Falls. The great supply of water under high head, available for driving turbine wheels, makes electrical power at Niagara very cheap

manner he was able to decompose water by sparks only one-tenth of an inch in length, from points of gold wire only one-thousandth of an inch in diameter. As the water was decomposed, gases were evolved from each of the gold wires and collected in separate vessels. In all cases, however, both hydrogen and oxygen gas were found in each of the glass vessels, so that in this respect, as Wollaston himself acknowledges, a difference exists between the decomposition produced by a current from a voltaic pile which produced the constituent gases separately and unmixed.

Wollaston decomposes water by sparks from frictional electric machines.

It was the invention of the voltaic cell that may be said practically to have started the science of electro-chemistry. For, as we have seen, very little was accurately known before this time. As soon as the genius of Volta had placed in the hands of scientific men a means of readily obtaining continuous and powerful electric currents, investigators in different parts of the world almost immediately employed this new agency in different fields of research. Although it was only on the 26th of June, 1800, that Sir Joseph Banks made public the details of Volta's invention to the Royal Society of London, yet, on the 2d of May, in the same year, Nicholson and Carlisle, in England, constructed a voltaic battery consisting of thirty-six English half-crowns alternating with as many disks of zinc and pasteboard soaked in salt water. With the current produced by this pile, they succeeded in decomposing water, and in separately collecting the hydrogen and oxygen gases resulting from such decomposition. They thus described this great discovery in the "Journal of Natural Philosophy and Chemistry," published in London in 1801:

Nicholson and Carlisle decompose water, May 2, 1800.

"In all these experiments it was observed that the action of the instrument was freely transmitted

through the usual conductors of electricity, but stopped by glass and other non-conductors. Very early in this course, the contacts being made sure by placing a drop of water upon the upper plate, Mr. Carlisle observed a disengagement of gas round the touching wire. This gas, though very minute in quantity, evidently seemed to me to have the smell afforded by hydrogen when the wire of communication was steel. This, with some other facts, led me to propose to break the circuit by the substitution of a tube of water between two wires. On the 2d of May we, therefore, inserted a brass wire through each of two corks inserted in a glass tube of half an inch internal diameter. The tube was filled with new river water, and the distance between the points of the wires in the water was one inch and three-quarters. This compound discharger was applied so that the external ends of its wire were in contact with the two extreme plates of a pile of thirty-six half crowns with the corresponding pieces of zinc and pasteboard. A fine stream of minute bubbles immediately began to flow from the point of the lower wire in the tube, which communicated with the silver, and the opposite point of the upper wire became tarnished, first deep orange, and then black. On reversing the tube, the gas came from the other point, which was now lowest, while the upper, in its turn, became tarnished and black. Reversing the tube again, the phenomena again changed their order. In this state the whole was left for two hours and a half. The upper wire gradually emitted whitish, filmy clouds, which, toward the end of the process, became of a pea-green color, and hung in perpendicular threads from the extreme half inch of the wire, the water being rendered semi-opaque by what fell off, and in a great part lay, of a pale green, on the lower surface of the tube, which, in this disposi-

Nicholson and Carlisle describe their experiment on the decomposition of water.

Electro-chemical effects produced by reversing direction of current.

tion of the apparatus, was inclined about forty degrees to the horizon. The lower wire, of three-quarters of an inch long, constantly emitted gas, except when another circuit, or complete wire, was applied to the apparatus; during which time the emission of gas was suspended. When this last mentioned wire was removed, the gas reappeared as before, not instantly, but after the lapse of four beats of a half-second clock standing in the room. The product of gas during the whole two hours and a half was two-thirtieths of a cubic inch. It was then mixed with an equal quantity of common air, and exploded by the application of a lighted wax thread.

"It might seem almost unnecessary to have reversed the order of the pile in building up, as reversing the tube must have answered exactly the same purpose. We chose, however, to do this, and found that when the zinc was at the bottom, its effects were reversed; that is to say, the gas still came from the wire communicating with the silver, etc.

"We had been led by our reasoning, on the first appearance of hydrogen, to expect a decomposition of the water; but it was with no little surprise we found the hydrogen extricated at the contact with one wire, while the oxygen fixed itself in combination with the other wire at the distance of almost two inches. This new fact still remains to be explained, and seems to point to some general law of the agency of electricity in chemical operations."

Separate evolution of hydrogen and oxygen

When it is desired to collect the gases evolved during the decomposition of water separately, a form of apparatus, called the voltameter, shown in Fig. 1, is employed. Here the battery terminals are connected with small plates of platinum that are immersed in water to which a small quantity of sulphuric acid has been added. Glass tubes H and

Sulphuric acid voltameter.

O, also filled with the acid and water, are placed over the platinum plates. On the passage of the electro-current, hydrogen appears in the tube placed over the cathode or negative terminal of the battery, and oxygen over the plate connected with the anode or positive terminal of the battery. The volume of the hydrogen liberated is twice that of the oxygen.

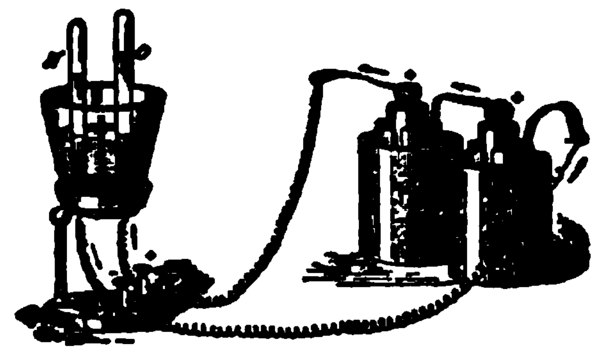


FIG. 1.—Sulphuric Acid Voltameter. Note the connections of the battery with the tubes in which the oxygen and the hydrogen are respectively liberated.

Pure water not capable of electro-chemical decomposition.

It was formerly thought that the effect of adding sulphuric acid to the water in which electro-chemical decomposition was occurring, was merely to lower its electric resistance. It is now, however, generally believed that pure water is a non-conductor of electricity, and can not be directly decomposed into its constituent gases; that when sulphuric acid is present it is this substance which is decomposed, hydrogen being directly liberated, and the acid being subsequently decomposed by the water and liberating its oxygen.

Davy's immortal discoveries of sodium, and potassium.

The announcement of the power of electricity to decompose chemical substances produced great excitement in the scientific world, and hosts of experimenters entered this attractive field of research. It was at first believed that new substances were produced by the action of the electric current, but careful researches, conducted by many investigators, especially by Davy, proved that the action of the current was not to produce new substances, but

merely to liberate substances that were already present in the bodies acted on. Davy carried on an extended series of researches in the domain of electro-chemistry, and, in 1807, announced to the Royal Society of London his immortal discovery that potash, which had before been regarded as an elementary substance, was composed of the hitherto undiscovered metallic element, potassium, combined with oxygen. Shortly afterward he extended this discovery, and showed that nearly the entire crust of the earth was formed of elementary metallic substances combined with oxygen. Davy gives the following description of this great discovery in a paper which he read before the Royal Society of London in 1808:

"The researches I had made on the decomposition of acids, and of alkaline and earthy neutral compounds, proved that the powers of electrical decomposition were proportional to the strength of the opposite electricities in the circuit, and to the conducting power and degree of concentration of the materials employed. . . . .

"The presence of water appearing thus to prevent any decomposition, I used potash in igneous fusion. By means of a stream of oxygen gas from a gasometer applied to the flame of a spirit lamp, which was thrown on a platina spoon containing potash, this alkali was kept for some minutes in a strong, red heat, and in a state of perfect fluidity. The spoon was preserved in communication with the positive side of the battery of the power of 100 of 6 inches, highly charged, and the connection with the negative wire was made by a platina wire.

Davy on electro-chemical decompositions.

"By this arrangement some brilliant phenomena were produced. The potash appeared a conductor in a high degree, and as long as the communication was preserved, a most intense light was exhibited

at the negative wire, and a column of flame, which seemed to be owing to the development of combustible matter, arose from the point of contact. . . . .

"A small piece of pure potash, which had been exposed for a few seconds to the atmosphere, so as to give conducting power to the surface, was placed upon an insulated disk of platina, connected to the negative side of the battery of the power of 250 of 6 and 4, in a state of intense activity; and a platina wire, communicating with the positive side, was brought in contact with the upper surface of the alkali. The whole apparatus was in the open atmosphere.

Experiments on pure potash

"Under these circumstances a vivid action was soon observed to take place. The potash began to fuse at both its points of electrization. There was a violent efferescence at the upper surface; at the lower, or negative surface, there was no liberation of elastic fluid; but small globules having a high metallic lustre, and being precisely similar in visible characters to quicksilver, appeared, some of which burned with explosion and bright flame as soon as they were formed, and others remained, and were merely tarnished, and finally covered by a white film, which formed on their surfaces.

Obtains metallic potassium.

"These globules numerous experiments soon showed to be the substance I was in search of, and a peculiar inflammable principle the basis of potash. I found that the platina was in no way connected with the result, except as the medium for exhibiting the electrical powers of decomposition; and a substance of the same kind was produced when a piece of copper, silver, gold, plumbago, or even charcoal, was employed for completing the circuit.

"The phenomenon was independent of the presence of air; I found that it took place when the alkali was in a vacuum of an exhausted receiver.

"The substance was likewise produced from potash fused by means of a lamp, in glass tubes confined by mercury, and furnished with hermetically inserted platina wires by which the electrical action was transmitted. But this operation could not be carried on for any considerable time; the glass was rapidly dissolved by the action of the alkali, and this substance soon penetrated through the body of the tube. **Electrolysis of fused potash.**

"Soda, when acted upon in the same manner as potash, exhibited an analogous result; but the decomposition demanded greater intensity of action in the batteries, or the alkali was required to be in much thinner and smaller pieces. With the battery of 100 of 6 inches, in full activity, I obtained good results from pieces of potash weighing from 40 to 70 grains, and of a thickness which made the distance of the electrified metallic surfaces nearly a quarter of an inch; but with a similar power it was impossible to produce the effects of decomposition on pieces of soda of more than 15 to 20 grains in weight, and that only when the distance between the wires was about 1/8 or 1-10 of an inch." **Obtains metallic sodium.**

CHAPTER II

ELECTROLYSIS

"This electrical force between two atoms at any distance is ten thousand million billion billion times greater than their gravitative attraction at the same distance. The force has an intensity, per unit mass (and, therefore, is able to produce an acceleration), nearly a trillion times greater than that of terrestrial gravity near the earth's surface."—*Modern Views of Electricity:* OLIVER LODGE

BETWEEN the years 1831 and 1840, Faraday conducted a series of investigations on the phenomena of chemical decomposition by the electric current, which resulted in a great increase in our knowledge of this branch of science. Some controversy had existed between scientific men as to the exact point in the electric circuit where electro-decomposition takes place. At first, nearly all investigators believed that the decomposition occurred at the poles or terminals of the battery, where the wires were dipped in the liquid solution to be decomposed. For example, when hydrogen and oxygen were separated by the passage of an electric current through water containing sulphuric acid, and the hydrogen and oxygen appeared at the negative and positive poles of the battery, respectively, they believed that these poles acted somewhat after the manner of a magnet in drawing apart or separating the constituent elements of the water, the hydrogen, an electro-positive element, being apparently drawn to the negative pole, and the oxygen, an electro-negative element, to the positive pole. At the same time a repulsion was also believed to exist

Electro-chemical decomposition apparently taking place at poles only.

at the poles, the positive pole apparently driving or repelling the positive hydrogen toward the negative pole, and the negative pole similarly repelling the negative oxygen toward the positive pole. Faraday rejected this belief, and pointed out the fact that it was not at the poles of the battery, but rather within the mass of the substance undergoing decomposition, that the separation occurred.

Faraday's investigations as to place where electro-chemical decompositions take place.

For the purpose of avoiding uncertainty by a continuance of the words in common use, Faraday suggested the use of the following new words: for the general process of decomposition of a substance by electricity, electrolysis; for the material that is thus broken up, the electrolyte;. for that terminal of the voltaic battery which is connected with the positive pole, the anode, and for that terminal which is connected with the negative pole of the battery, the kathode; or, as it is sometimes written, cathode; for the separate atoms, or groups of atoms, into which the molecules of the electrolyte are separated, the ions; the ion which appears at the anode to be called the anion, and that which appears at the kathode to be called the kathion. Since it is the electro-negative ions that appear at the anode, or electro-positive terminal, the anions are necessarliy electro-negative ions, or radicals; while for the same reason the kathions are electro-positive ions.

Electrolysis and the electrolyte.

Anode and kathode.

Ions, or anions and kathions.

As a result of extensive researches in electro-chemistry, Faraday established the fact that, during any electro-chemical decomposition, the amount of the electrolyte decomposed depends only on the amount of electricity that has passed, and is not affected by changes in the size of the electrodes, or by the degree of dilution of the electrolyte. Consequently, if a current of one ampère, or one coulomb of elec-

Amount of electro-chemical decomposition dependent only on quantity of electricity passing.

tricity per second, in a certain time, liberates a certain amount of copper from a solution of copper sulphate, then two ampères will, in the same time and under the same conditions, liberate twice as much copper, and three ampères, three times as much, etc. Faraday also showed, where several electrolytic cells, or vessels in which chemical decomposition is taking place, are connected in series, in the same circuit, so that the same quantity of electricity passes through each, that if they all contain a solution of copper sulphate, exactly the same quantity of copper will be deposited in each cell; but that if one of these cells contains, say, a solution of copper sulphate, and the other water acidified with sulphuric acid, that the weights of the copper and hydrogen liberated will not be the same in each cell, but will be in different amounts; *i.e.*, in proportion to the chemical equivalents. For example, one coulomb of electricity will liberate .0003281 grammes of copper from a solution of copper sulphate, and .00001038 grammes of hydrogen from water containing sulphuric acid. That is, a weight of copper 31.59 times greater than that of hydrogen will be liberated. This is the proportion of the chemical equivalents of copper to hydrogen, or as 31.49 is to 1. This will be equivalent to 1.181 grammes of copper per hour, or .0373 grammes of hydrogen per hour.

Quantities of copper and of hydrogen liberated by one coulomb of electricity.

Use of the sulphuric acid voltameter.

Since the amount of electro-chemical decomposition is thus entirely dependent upon the quantity of electricity that passes, electro-chemical decomposition may be employed as a means for measuring the quantity of electricity that passes in a given time in any circuit. The sulphuric acid voltameter, described in connection with Fig. 308, is employed for this purpose. A more convenient form of voltame-

ter, however, consists in an instrument called the copper voltameter, in which a solution of copper sulphate is electrolyzed by passing the current to be measured between two plates of copper immersed in a solution of copper sulphate. During this passage the copper is slowly dissolved from the plate connected with the anode, and deposited on the plate connected with the kathode. By ascertaining the increase in the weight of the kathode, the amount of current that has passed in a given time can be readily calculated, since, for every .0003281 grammes of copper deposited, one coulomb of electricity has passed. Edison's electro-chemical meter, already referred to in connection with the discussion of the incandescent lamp, is based on this principle.

Copper voltameter.

It will be well to call attention here to the fact that all substances are composed of a very great number of separate atoms, or groups of atoms, called radicals or ions; that the molecules are formed by the union or combination of an electro-positive atom or group of atoms with an electro-negative atom or group of atoms; and that, when an electrolyte is decomposed into its constituent atoms or radicals, or what Faraday called ions, the electro-positive atom, radical, or ion, appears at the negative terminal, or kathode, while the electro-negative atom, radical, or ion, appears at the electro-positive terminal, or anode. As a rule, hydrogen, and the metals generally, act as electro-positive atoms or ions, while acid substances, oxygen, chlorine, and the non-metallic substances, generally act as electro-negative atoms, ions, or radicals.

Electro-positive and electro-negative character of atoms, ions, or radicals.

Cause of chemical affinity.

It was formerly believed—since, whenever electrolysis occurs, the molecules of the electrolyte are broken up into groups which appear at the opposite

poles of the voltaic cell furnishing the decomposing current—that the cause of such electro-chemical decomposition was the superior and stronger attraction which the poles of the decomposing source exerted on the opposite atoms or ions than that which they exerted on each other. Such views, however, were afterward modified, not only by reason of the great length of the liquid path through which such decomposition can take place, but also by reason of the curious fact that the atoms or ions are liberated only at the free ends of such liquid paths where the positive or negative terminals of the decomposing source are connected with the liquid.

Electro-chemical decomposition in syphon-connected vessels.

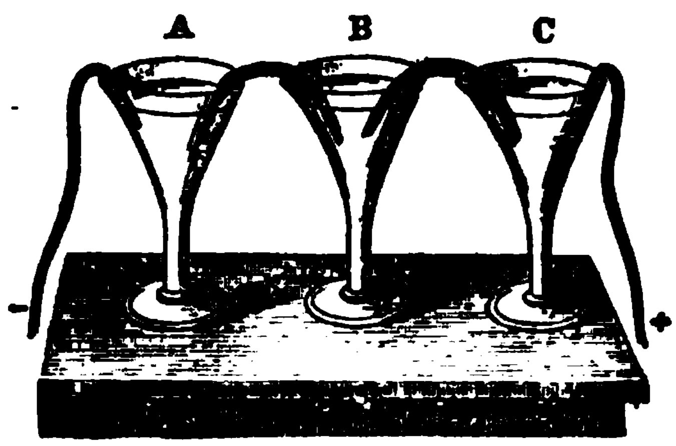


FIG. 2.—Electro-chemical Decomposition in Siphon-connected Vessels.

Take, for example, the experiment shown in Fig. 2, where the platinum wires + and — connected with the voltaic battery are inserted, as shown in two of the three glasses represented. These glasses are connected by means of a bent mass of asbestos or paper moistened with the same solution as was placed in the glasses; in this case a solution of copper sulphate. When under these circumstances a current passes through the circuit entering at C, and passing out at A, and being connected from one glass to another through the arched masses of asbestos or moistened paper, metallic copper appears at the terminal in A and an acid in that in C, apparently no change occurs in the intermediate glass B. Moreover, if in place of the solution of copper sulphate,

a solution of sulphate of soda, colored with a vegetable blue, is placed in all the glasses, and employed to moisten the connecting bands of asbestos or paper, on the passage of the current, the negative radical, in this case an acid, appears at C only, where it turns the blue solution red; and soda, the positive radical, appears at A only, where it turns the liquid green. Apparently no effect whatever is produced in the liquid in the intermediate glass B, which retains its blue color.

Liberation of acid and basic radicals indicated by the change of color of a vegetable blue.

In view of the above experiment, it was argued that in such cases of electro-chemical decomposition, there is a chain of polarized molecules extending between the anode and the kathode.

FIG. 3.—Hypothesis of Grötthuss as to Nature of Electrolysis.

In this connection, in 1805, Grötthuss suggested the following hypothesis to account for the phenomena of electrolysis. Let A, B, Fig. 3, represent, respectively, the anode and the kathode of a decomposing cell containing hydrochloric acid, a substance formed by the combination of hydrogen and chlorine. Before the passage of the current, the molecules have no definite arrangement, some of them being turned in one direction and some in another. This is represented in the row of molecules at 1. As soon as the

Hypothesis of Grötthuss for electrolysis.

terminals of the battery are inserted in the liquid, a polarization occurs. All the negative sides of the molecules are turned toward the anode or positive terminal,and all the positive sides toward the kathode or negative terminal, as indicated at 2 in the figure.

Liberation of atoms, radicals, or ions, at kathode and anode only, and interchange of same throughout polarized chains.

When decomposition occurs, the freed atoms of hydrogen and chlorine are liberated at the surfaces of the negative and positive terminals respectively; the hydrogen atoms in the molecules that are in contact with the negative terminal, are liberated at the surface of such terminal, and the chlorine atoms, with which they were formerly united, enter into combination with the hydrogen of the molecules that are next in the chain between the electrodes; the freed atoms of chlorine in these molecules, in a similar manner, enter into combination with the hydrogen atoms of the next molecule in the chain. This process is carried on throughout the entire chain, until the atoms of chlorine at the end of the chain, having no freed atoms of hydrogen with which to combine, are liberated at the surface of the positive terminal.

Grötthuss' theory, which was proposed in 1805, was generally accepted by scientific men for many years. Now, however, it is universally rejected.

Clausius questions the Grötthuss theory

In 1857, Clausius pointed out the fact that Grötthuss' theory is not in strict accordance with our ideas of the conservation and transformation of energy. He showed that if this theory were correct, an electrolytic solution could not become a conductor of electricity until the energy of the current was sufficient to effect the decomposition of the molecules, and that, moreover, where this decomposition was effected the flow of current should suddenly become great, many molecules being simultaneously decomposed at this time.

Now, as is well known, when the electrodes of the same metal, say of copper immersed in a solution of copper, say of copper sulphate, have an electric current sent between them through the copper solution, the metal is deposited on one of the electrodes and dissolved from the other when an amount of energy is expended by the electrolyzing current that is far less than that which Grötthuss' theory would require. He therefore concluded that the ions of the electrolyte, or at least some of the ions, must exist in a free or uncombined condition, free to move through the electrolytic solution before the electrolyzing current is applied. In his opinion, this current does not cause the decomposition, but merely directs the free ions in their movements toward the opposite electrodes.

The refutation.

Hittorf was another objector to Grötthuss' theory, and about the time of Clausius began his studies on what he termed the "migration of the ions," or their movements toward the opposite electrode of the electrolyzing source.

In 1881, H. von Helmholtz, in the Faraday lecture, delivered in London, laid the foundation of a new electro-chemical theory which brings the facts of Faraday's theory into accord with later views. Helmholtz asserted that when an electrolytic circuit is closed, the kathions, which are charged with positive electricity, are attracted to the kathode, and the anions, which are charged with negative electricity, are similarly attracted to the anode; that the ions are set free only at the electrodes and not throughout the mass of the electrolyte, the liberation taking place at the surface of the electrode, by reason of those quantities of electricity of opposite kinds which are carried to the electrodes by the decomposing current, the opposite charges neutral-

Helmholtz on electrolysis.

izing each other. When this occurs, the ions cease to be in the ionic condition, or, quoting the language of Helmholtz, "The same definite quantity of either positive or negative electricity moves always with each univalent ion, or with every unit of affinity of a multivalent ion, and accompanies it during all its motions through the interior of the electrolytic fluid. This quantity we may call the electric charge of the atom. . . . If we accept the hypothesis that the elementary substances are composed of atoms, we can not avoid concluding that electricity also, positive as well as negative, is divided into definite elementary portions, which behave like atoms of electricity. As long as it moves about in the electrolytic fluid, each ion remains united with its electric equivalent or equivalents. At the surface of the electrodes decomposition can take place if there is a sufficient electro-motive force, and then the ions give off their electric charges and become neutral."

An atomic theory.

The exact manner in which the above neutralization is effected is uncertain.

The theory of Arrhenius.

In 1887, Arrhenius proposed a theory of electrolytic dissociation not unlike that of Helmholtz. Arrhenius asserted: That in electrolytic solutions the molecules are dissociated into their two ions, which are electrically associated with their respective electric charges before the passage of the electrolyzing current. That under ordinary conditions, before the electrolyzing current passes, their ions move irregularly to-and-fro among the water molecules, an ion sometimes approaching and sometimes receding from an ion of the opposite kind. That when a difference of potential is established between the electrodes of the electrolytes and by connection with an electric source, the ions no longer move about irregularly, but follow definite paths, the kathions

moving toward the kathode, and the ions moving toward the anode, and that, moreover, these movements take place with definite velocities, which vary with the chemical constitution of the ions.

The difficulty of crediting the existence of free ions in a solution of some substances, such as sodium chloride—*i.e.* of the possible existence of atoms of free sodium, which ordinarily combine energetically with the oxygen of water liberating the hydrogen, or of chlorine, which should apparently manifest their presence by their characteristic chemical properties, or that these substances could be taken harmlessly into the human system—has proved a stumbling-block to many chemical physicists. It would appear, however, that elementary matter in the ionic condition, where certain quantities of energy are associated with the ions, possesses properties that are in many respects entirely different from that of the molecules of the free elements. This is only another indication that our ideas of the constitution of the elementary atoms need very considerable change, as has already been pointed out in connection with our remarks on the fragmental atomic condition of matter.

Objections.

With some modifications, the dissociation theory of Arrhenius is generally adopted. It would appear, however, that much yet remains to be discovered concerning the phenomena of electrolysis that will probably remain undiscovered until we know more concerning the ultimate constitution of the elementary atoms.

Theory of Arrhenius generally adopted.

All substances capable of being electrolyzed, or decomposed by the passage of an electric current, must possess the power of conducting electricity.

There are, therefore, two general classes into which electric conductors can be divided, *i.e.*, those through which a current can pass without producing any chemical changes therein, as in metallic conduction, and those through which such passage is invariably attended by the production of chemical changes, as in electrolytic conduction.

Metallic and electrolytic conduction.

It is evident that whenever an electrolyte has been separated into its constituent elements or radicals, there must be a tendency for these to re-combine and again form the molecules of the electrolyte. Take, for example, the case of hydrogen and oxygen, that have been separated from the molecules of water in the sulphuric acid voltameter. Here a tendency must exist for these two gases to re-combine. This tendency manifests itself in the production of a counter electro-motive force of 1.474 volts, which opposes the passage of the decomposing current through the water. Consequently, decomposition can not take place unless the E.M.F. of the current is at least as great as 1.474 volts. It is this C.E.M.F., as we shall shortly see, that produces the electric current in the now well-known electrical apparatus called storage batteries.

Counter E.M.F. in decomposition cell.

In the case of the copper voltameter, where plates of copper are immersed in a solution of copper sulphate, there is no opposing counter-motive force developed so that a very feeble current is capable of causing chemical decomposition.

Cases where C.E.M.F. is absent.

It may be interesting here, as an example of the modern theory of chemical affinity, to quote Prof. Oliver Lodge, in his "Modern Views of Electricity":

"These are undoubtedly the forces with which

chemists have to do, and which they have long called chemical affinity.

"But it may be asked, If the atoms in each molecule cling together by their electro-static attractions, and there are an enormous number of atoms between two electrodes, how comes it that a feeble E.M.F. can pull them apart and effect decomposition? Moreover, how can the E.M.F. needed to effect decomposition help varying directly with the thickness of fluid between the plates? It does not depend on anything of the kind; the length of liquid between the electrodes is absolutely immaterial. This proves that throughout the main thickness of liquid no atoms are torn asunder at all. Probably they frequently change partners, one pair of atoms not always remaining united, but occasionally getting separated and recombined with other individuals. During these interchanges there must be moments of semi-freedom, during which the atoms are amenable to the slightest directive tendency, and it is probably these moments that the applied E.M.F. makes use of."

Lodge on electrolytic decomposition

CHAPTER III

ELECTRO-METALLURGY

"From the date of the discovery of Voltaic Electricity, or Voltaism, in the year 1799, experimental philosophers in all parts of the world increasingly devoted their labors to the investigation of the phenomena which the electric current, generated by chemical action upon the metals, is capable of producing, until, step by step, the great Art of Electric Metallurgy was called into existence, and brought to its present high state of development."—*Electro-Deposition:* WATT

Electro-metallurgy. THE art of electro-metallurgy embraces a variety of processes, employed for the precipitation of metals from their solutions by the gradual action of an electric current. Electro-metallurgy may be divided into three general classes. It includes the art of electrotyping, whereby copies of types, medals, wood-cuts, plaster casts, and various other objects may be obtained. **Electro-typing or galvano-plastics.** This branch of the art is sometimes called galvano-plastics, or the art of cold casting metals by the agency of electricity. Electro-metallurgy also includes the art of **Electro-plating.** electro-plating, or covering the surfaces of the baser metals with gold, silver, platinum, nickel, etc. Finally, electro-metallurgy also includes the art of **Electro-refining.** electro-refining, or the art of reducing metals from solutions of their ores.

Although, as we have seen, it was known shortly after the invention of the voltaic cell that coatings of metals could be obtained by electro-chemical decomposition, yet it was not until a much later date that such processes were actually applied to any practical purposes.

It would appear that the first practical application was made by Louis Brugnatelli, Professor of Chemistry in the University of Pavia. This early investigator succeeded in covering two large silver medals with gold by electro-deposition. An account of this process was published in the "Philosophical Magazine," of London, in 1805. Brugnatelli

"I have lately," says he, "gilt in a complete manner two large silver medals, by bringing them into communication by means of a steel wire with the negative pole of a voltaic pile, and keeping them, one after the other, immersed in ammoniuret of gold, newly made and well saturated."

Brugnatelli's discovery does not seem to have attracted much attention, and nothing further was heard of this application, nor does anything appear to have been done in this field of practical work until 1828, when De la Rive, of France, successfully gilded platinum and silver wires for the purpose of employing them as negative electrodes in solutions of gold. De la Rive did not publish any description of this process until the year 1840. De la Rive gilds platinum wires in 1828.

In 1834, Henry Bessemer electro-plated with copper castings of lead, so as to permit them to be used for ornaments for mantel-pieces. Bessemer copper-plates lead-castings in 1834.

In 1836, De la Rue described a modified form of Daniell's voltaic cell, of which he published the following account:

"The copper plate is also covered with a coating of metallic copper, which is continually being deposited; and so perfect is the sheet of copper thus formed, that, being stripped off, it has the counterpart of every scratch of the plate on which it is deposited." De la Rue in 1836.

It will be observed that the applications above referred to all pertain to the art of electro-plating. Although the observation of De la Rue showed the possibility of obtaining casts by metals deposited in the cold by electro-chemical decomposition, and thus undoubtedly suggested the possibility of the art of electro-typing, or galvano-plastics, yet no particular use was ever made of it. The merit of the discovery of the art of electro-typing appears to be due to two separate workers; viz. to Jacobi in Russia, and to Spencer in England. The work of these two investigators appears to have been entirely independent of each other. Both inventors succeeded in producing coins and medals in intaglio, that is, they deposited a layer of copper over the surface of a metal, and afterward separating it, obtained a sunken, hollow mold, with the characters appearing as if cut or engraved on the coin or medal. They also succeeded in obtaining copies of objects in relief. Both inventors pointed out the necessity of employing saturated solutions of the metallic salts for use in the electrolytic baths, in order to obtain good adherent deposits of the metals.

Pioneer work of Jacobi and Spencer in electro-typing.

In October, 1838, Jacobi, of Russia, made the announcement that he was able to employ the electric current in reducing copper from its solutions for the purpose of producing metals, stereotype plates, ornaments, and for the making of calico printing blocks and patterns for paper hangings. A translation of Jacobi's original paper on galvano-plastics, or the process of cohering copper into plates or other given forms by means of galvanic action on copper solutions, appeared in Volume VII. of the "Annals of Electricity." In this publication Jacobi makes the following statement as to the origin of the discovery:

Jacobi's announcement in 1838.

"In the year 1837, while in Dorpart, I had a series of experiments to carry on, upon the strength and duration of galvanic currents produced by an apparatus constructed upon similar principles; but instead of copper plates I furnished myself with copper cylinders, surrounded by animal bladders, for the purpose of keeping the liquids separate. As these bladders became damaged by use, they were taken out, and gave occasion to inquire into the form in which the copper was reduced. It was found on the surface of the copper cylinders, and in the inner folds of the bladders, partly in thin bars and partly in large and small corns of crystalline texture, which to those beneath showed not the least attachment. Afterward, however, while continuing to remove these corns, etc., it was found that they adhered more closely together, and required some force to separate them; it was also found that the copper cylinder itself was completely covered with a layer of reduced copper, which, to my astonishment, was removed in large, well-connected plates. As no mention had hitherto been made of such regular formations of reduced copper, these corns, etc., were held of a high interest. I must confess, indeed, that I was myself surprised, as I remarked at the time, that some fine file marks and indentations from hammer blows, which were conspicuous on the surface of the copper cylinders, had, with the greatest degree of accuracy, given corresponding forms to the plates of reduced copper."

Jacobi's published statement of his discovery.

File and hammer marks accurately reproduced in copper deposited in voltaic cell.

On May 8, 1839, Spencer gave notice that he would read a paper, entitled "The Electrotype Process," before the Liverpool Polytechnic Society. This paper, however, was not read until September 12, 1839. Spencer claims that the results described in this paper were obtained from experiments extend-

Spencer's published statement in 1839.

ing back as far as 1837. His invention embraced the following point; *i.e.*, a method of engraving in relief on a plate of copper. In order to do this, a copper plate was coated with a thin layer of wax, and the wax was cut away by a graving tool in the desired form, so as to expose the copper plate below. The plate was then covered with an acid capable of attacking copper, so that the parts not protected by the wax covering were eaten away by the acid. A layer of copper was then deposited in the sunken lines so obtained, so as to stand out in relief.

Spencer's process of engraving in relief on copper.

Spencer's paper also embraced a method of obtaining a solid voltaic plate, having its lines in relief. This was done by taking an electrotype of an engraved plate, in which case, as its lines are sunken in the plate, they will stand out in relief in the electro cast, when it is separated from the engraved plate.

Another process for obtaining copper plates engraved in relief.

In order to obtain fac-similes of coins, medals, etc., Spencer employed two distinct processes. In one of these he obtained an electro mold by depositing a thin layer of copper on the surface of the coin, and afterward obtained an electro cast from this mold. By another process he first obtained a lead mold, by pressing a plate of lead with great force against the surface of the coin, and then took an electro cast of this mold.

Fac-similes obtained of coins, medals, etc.

Spencer also employed, for obtaining objects in relief, the process of forming molds of such objects in plaster of Paris or clay, rendering these molds electrically conducting by covering them with a thin layer of bronze powder or gold leaves. He also describes a process for obtaining any number of copies

Use of molds of plaster of Paris and wax.

MAKING ELECTROTYPE PLATES FOR A MAGAZINE

Most periodicals other than newspapers are printed from electrotypes. The photograph shows electrotypers watching the formation of the copper deposit in the electrolytic bath on the plates to be used for magazine printing

from an already engraved copper plate. This he did by pressing a plate of lead with great force against the copper plate, and employing the lead mold so obtained for the reception of the electro cast.

Murray's use of plumbago to render non-conducting surfaces electrically conducting.

An important discovery in the art of galvano-plastics was made by a Mr. Murray, of England, who was the first to employ graphite or plumbago for covering non-conducting surfaces, so as to render them electrically conducting for receiving electric deposits of electro-typing. The advantage of Murray's discovery lies in the fact that the hydrogen, which tends to be liberated at the surfaces covered with plumbago, clings or adheres to the carbon so strongly that it reduces the copper salt rather than be detached, a property that is very desirable in electro-type processes.

Elkington and Ruolz.

In 1840, Elkington took out a patent in England for electro-plating by the battery. In the same year, Ruolz took out a patent for a similar purpose. Elkington applied his process to electro-plating on a commercial scale, for the purpose of covering the surfaces of the baser metals, such as German silver, iron and lead, with thin coatings of gold and silver.

FIG. 4.—The Art of Electro-plating.

Process of electro-plating.

The process of electro-plating is one of extreme simplicity. The metal to be deposited is placed in the form of a solution of one of its salts in a suitable tank, such as that represented in Fig. 4.

The objects to be plated are connected with the negative terminal of an electric source—in this case, a single voltaic cell—and placed in the solution of metal directly opposite a plate of the same metal that is in the solution, and connected to the positive terminal. If, for example, the solution contains sulphate of copper, then a plate of copper is connected with the positive terminal of the battery or anode. On the passage of the current, an adherent coating of metallic copper is deposited over the surface of the object connected with the negative terminal or cathode.

How the strength of the plating solution is kept constant during the process of electro-plating.

The extreme simplicity of the process is not limited to the above combination of parts. In addition, there exists no necessity for maintaining the strength of the solution of copper sulphate or other metallic salt, owing to the weakening of the solution by the deposit of a part of the copper or other salt on the article to be plated. This is for the following reason: On the passage of the current, as one molecule of the metallic salt is decomposed, say one molecule of copper sulphate, and its atom of copper deposited on the object connected with the kathode, the acid radical, which is liberated at the anode, enters into combination with the copper plate attached thereto, and forms a new molecule of copper sulphate, thus maintaining the strength of the solution. It is for this reason that the plate connected with the anode in a plating bath is called the soluble

Soluble anodes.

anode. Where silver, gold, etc., are to be deposited, plates of silver, gold, etc., are connected with the anode. It is customary to electro-plate a number of articles at the same time, as is the case in the appara-

Silver-plating.

tus represented in the preceding figure, where a number of spoons, etc., are being electro-plated with silver, or silver-plated, as this particular process is

sometimes called. In this case, therefore, a plate of silver is connected with the anode, and the articles to be plated suspended in the silver bath from a metallic rod connected with the kathode.

Where such substances as iron, pewter, etc., are to be either silver-plated or gold-plated, they are first covered with a coating of copper, on which the silver or gold is afterward deposited. A firmer adherence is thus secured. It has been found possible, by employing suitable solutions, to deposit brass by electro-plating on the surfaces of conducting bodies. Copper-plating sometimes employed before silver or gold-plating articles.

Since the advent of the dynamo-electric machine, voltaic batteries are no longer employed in electroplating or electro-typing on a commercial scale, the shunt-wound dynamo being found far cheaper and more efficient for such purposes. Since the E.M.F.'s required for such purposes are comparatively weak, such machines are generally wound for from five to ten volts. The current produced, however, is large, so that heavy conductors are employed for the series coils on the field and armature. Use of dynamos for furnishing plating currents.

A machine suitable for electro-plating is represented in Fig. 5. This machine is capable of producing, at 500 revolutions, a current of 1,000 or 2,000 ampères at a pressure of from 6 or 12 volts, as will be seen. This machine is of the multipolar type.

In the process of electro-typing, the name generally given to galvano-plastics in this country and in England, it is first necessary to obtain a suitable mold or impression of the article to be reproduced. Suppose, for example, that this be a wood-cut such How an electro-type or electro of a wood-cut is prepared.

as is employed for printing. In order to greatly increase the number of impressions capable of being taken from a wood-cut, an electro-type, or, as it is generally called, an electro, is prepared. Here the first step is to obtain a suitable mold or impression of the wood-cut. This is done by placing the surface of the wood-cut against a plate of wax, and then forcing the wax into all the interstices by powerful pressure. The surface of the wax mold is then rendered electrically conducting by dusting it with

FIG. 5.—Electro-plating Machine of the Multipolar Type.

Coating the back of the metallic shell with tin.

finely powdered plumbago, and a thin layer or coating of copper is deposited in the mold by connecting it with the negative terminal of a battery, and placing it in a bath of copper sulphate opposite a plate of copper connected with the positive terminal. When a sufficiently thick coating of copper has been obtained, the copper shell is detached from the mold, and stiffened by a backing of type metal. In order to ensure the adherence of the type metal to the copper, the shell is first coated with metallic tin.

The electro is then prepared for printing by mounting it on a wooden block or backing. Gutta-percha or gelatine is sometimes employed in place of wax for the preparation of the molds. While an ordinary wood-cut is only able to print a limited number of clear impressions before wearing out, say 10,000 at the most, an electro-type is able to print a very much greater number of copies. Moreover, since the wooden block is uninjured by the process, an indefinite number of electros can be obtained from it. Backing the electro.

Copper and steel plate engraving can be duplicated by a similar process. In this manner the plates required for the printing of postage stamps, bank notes, and playing cards can readily be duplicated in any desired number. Many impressions of the original engraved plate required for a postage stamp are taken and united together on the same plate, so that several hundred stamps may be printed by a single impression. The immense number of postage stamps required for daily use, in large countries like the United States, will enable one to appreciate the great practical value of this invention. Duplication of copper-plate and steel-plate engravings. How postage stamps are printed.

Where the copper is carefully deposited, the surfaces of the electros are so hard that they can be employed to an almost indefinite extent. For example, electros have been prepared for use in such newspapers as the London "Times," from which they have been able to produce as many as 20,000,000 copies without very marked injury. Great number of impressions possible from single electro.

Another practical application of the art of electrotyping is seen in the correction of engraved plates, such as might be required for the introduction of new details on topographical maps. Here the portions to be changed are removed by being cut away, and a deposit of metallic copper is obtained by the Correction of copper engraving plates.

electro-typing process, on which the corrections are afterward engraved.

Method of obtaining an electro-cast of a medal.

Where medals, statuary and other objects are to be copied by electro-typing, it would not, of course, be practicable to deposit the metal directly upon the surface of the article, since when such deposit had been stripped off, it would give a reverse impression, or an intaglio, like that of an ordinary mold. In order to obtain the desired cameo impression, that exactly reduplicates the form of the object, a

Fig. 6.—Method of Obtaining an Electro-cast of a Medal.

mold must first be obtained, and the electro-cast made in this mold. Of course the electro-cast itself might be employed as a mold, but it is much simpler to employ a mold obtained by the use of wax or gutta-percha, as already described, and after rendering its surface electrically conducting, to deposit the copper directly in it in the manner shown in Fig. 6, at the right-hand side. Here only those parts of the mold are rendered conducting on which it is desired to deposit the copper, contact being obtained with such surfaces by means of copper wires attached, as in the figure, to the conducting surfaces by means of slender wires. The complete medal thus

obtained is represented at the left-hand side of the figure.

Method of obtaining electro-casts of large vases and statues.

Where the object to be reproduced consisted of large vases or pieces of statuary, a difficulty was found to exist in practice of obtaining equally thick deposits over all portions of the mold. If soluble anodes were placed inside such objects, another difficulty arose from their rapid and unequal solution. At first this was avoided by the employment of insoluble electrodes, consisting of a bundle of plati-

FIG. 7.—Method of Obtaining Electro-casts of Large Objects.

num wires surrounding the mold on all sides without touching it. In order to maintain the strength of the copper solution, bags of porous material, containing crystals of copper sulphate, were placed inside. The method, however, of employing bundles of platinum wire was not found to be entirely satisfactory. Planté, however, removed the difficulty by replacing the platinum wires by a core of lead, pierced with holes. This core was given the same outlines as those of the object to be reproduced. The general method of its use will be seen from an inspection of Fig. 7, where the mold is repre-

sented at the left-hand side of the figure, and the finished vase at the right-hand side. By such means it has become possible to reproduce heroic statues, even when they reach the size of nearly thirty feet in height.

Electric refining of metals.

Various processes have been devised for the electro recovery and refining of metals. One of the simplest of these, employed for the refining of copper, consists in placing the impure copper to be refined as a soluble anode in a bath of copper sulphate,

Fig. 8.—Electrolytic Generators, Westinghouse Company's Type.

from which it is electrically deposited in a pure state on a plate of copper connected to the kathode, the impurities being left in the bath. Where this process is employed for the treatment of large quantities of metal, as at the works of the Boston & Montana Consolidated Copper Mining Company, at Great Falls, Montana, very large electric currents are required.

Use of electrolytic generators in the electric refining of copper at Great Falls, Montana.

These are obtained by specially constructed dynamos, called electrolytic generators, driven by water-power. In the process employed here, a number of separate tanks, in which the decomposition takes place, are connected in series so that the E.M.F.

of the generators can be increased. Two electrolytic generators of the Westinghouse Company's type are shown in Fig. 8. Each of these is capable of delivering a current of 4,500 ampères at a pressure of 180 volts when driven at a speed of 130 revolutions per minute. These dynamos are directly connected to the driving turbines. Heavy copper conductors are required to carry the electric current from the generators to the decomposing tanks, a distance of about two-fifths of a mile. These conductors consist of a number of copper bars, the area of

Copper conducting circuit.

FIG. 9.—Conductors for Copper Refining Plant at Great Falls, Montana.

whose cross-section is 24 inches. They are supported as shown in Fig. 9, the separate bars being soldered together. These conductors are provided with suitable expansion joints.

Electrical protection of metals.

In every voltaic cell, where the voltaic couple consists of two different metals, the electrolyte acts on or corrodes one of the metals only, the other metal being left entirely unaltered. It is the electro-positive metal that is so attacked, the electro-negative metal not only being left unattacked, but even being

preserved from any corrosive action while it is associated with the electro-positive metal. By thus associating one metal in the form of a voltaic couple with another metal which is alone corroded, it is possible to thoroughly protect the other metal. Various applications have been made of this fact, in order to electrically protect metals from corrosion.

Davy's plan for the electric protection of the copper sheathing of ships' bottoms.

Sir Humphry Davy proposed to protect the copper sheathing of ships' bottoms from corrosion by sea water by attaching pieces of zinc to the sheathing. He succeeded so well that his process entirely failed, although for another reason; for, heretofore, the ships' bottoms had been protected from fouling by the accumulation of seaweed and barnacles by reason of the poisonous copper salts which covered the surface of the sheathing. Davy's method protected the bottom of the ship so thoroughly that these accumulations, no longer checked, increased so rapidly as to seriously impede the ship's progress through the water.

Galvanized iron.

The process of preparing galvanized iron—that is, by covering the surface of the sheets or other articles of iron with a thin layer of zinc by dipping the sheets in a mass of molten zinc—is based on this fact, the galvanized iron being electro-negative to zinc, so that if corrosion occurs a voltaic couple is formed, and the iron will be protected while any zinc remains uncorroded. Perhaps, however, an equal reason for the protection of iron so covered is found in the fact that there is soon formed on the surface of the zinc an insoluble oxide of zinc, which prevents any further corrosion. Ordinary tin-ware, which consists of sheets of iron that are covered with a thin coating of metallic tin, afford an excellent example of the coating being formed of an electro-negative

Why articles formed of tinned iron, rust so rapidly when the iron is exposed.

metal, the iron being electro-positive to the tin. When, therefore, the iron is exposed, as by a deep scratch, the ware rapidly rusts, since the corrosive elements attack the iron, the positive metal, which thus serves to protect the tin.

In the early history of the electric street railway cars, where but little care was taken to ensure a good connection between the ends of contiguous rails on the track, and where, therefore, the ground acted as the principal part of the return circuit, serious difficulties were experienced from the electrolytic corrosion of the gas and water pipes that were buried in the streets over which the railroad tracks passed.

Points where electrolytic corrosion takes place in trolley ground-return circuits.

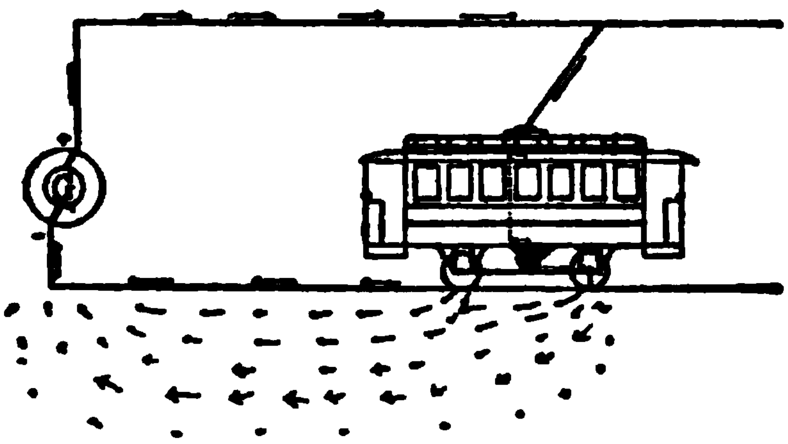


FIG. 10.—Simple Trolley Circuit, showing ground-return through tracks, etc.

Here, however, as in the cases above referred to, the corrosion only takes place at those metallic surfaces where the current leaves the metals and enters the ground, while, where the current leaves the ground and enters the metals, there will not only be no corrosion of the metals but even a protection. In the case of the circuit of the generator and the car shown in Fig. 10, where the positive pole of the generator is connected with the trolley wire, and the return current passes through the track and so to the ground, and where the electric resistance of the track is so small as to be negligible, the current will return to the generator almost entirely through the track. On the contrary, however, if the track be

disconnected at some point, as, for example, at an unbonded rail, the current will leave the track and enter the ground. Consequently, the better the bonding the smaller will be the amount of trouble occasioned by electrolytic corrosion. In the case shown in Fig. 10, in accordance with the above principles, if there are no gas or water pipes in the neighborhood, corrosion will take place on the surface of the track, and this will cause but little trouble. But suppose that there is, in the neighborhood of such track, as is the case in practically all large cities, a buried gas or water pipe, as represented in Fig. 11, then the current entering such pipe may form a part of the return circuit, and serious

Why good rail-bonding will practically prevent electrolytic corrosion.

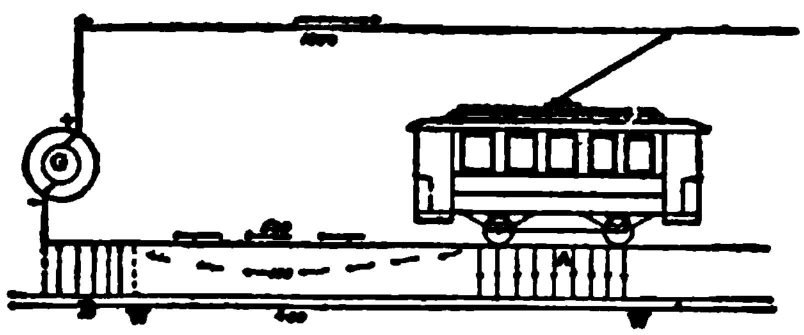


FIG. 11.—Trolley Circuit. Electrolytic corrosion will occur on the tracks at A, and on the waterpipes at B, where the current leaves the metals.

damage may result from corrosion at such points where the current leaves the pipe. This is especially great in the neighborhood of the power station. The corrosion of the tracks would take place at A, where the current leaves the tracks, while the corrosion of the iron pipes would take place at B, where the current leaves the pipes. By connecting the system of water-pipes with the grounded terminals of the generator by conductors, indicated by the dotted lines, the amount of electrolysis at B would be greatly lessened by the fact that the greater proportion of the current would now pass through the new connection. By reversing the direction of connection—*i.e.*, by connecting the positive terminal of the generator with the track, and the

Points where corrosion will occur where rails are imperfectly bonded.

negative terminal with the trolley wire—the positions of corrosion, as indicated in the preceding figure, will be reversed, and this plan is sometimes adopted. Wherever a good system of rail bonding, with sufficient ground return conductors,

Appearance of iron pipe destroyed by electrolytic corrosion.

FIG. 12.—Specimen of Iron Pipe Destroyed by Electrolytic Corrosion.

is employed, trouble arising from electrolysis is comparatively insignificant. Unless, however, such precautions are taken, corrosion to the extent of that represented in Fig. 12, which shows the serious action on a water pipe, may occur.

CHAPTER IV

STORAGE BATTERIES

"It is well known that the history of the storage cell is essentially that of the lead cell discovered by Planté, in 1860, in which lead peroxide is the depolarizing substance. An enormous amount of labor has, in the aggregate, been expended upon the improvement of this cell in the hands of experimentalists. As a result of that labor, the storage battery has at last become a recognized adjunct to direct-current central stations, but it has limitations that seem to withstand further attempts toward improvement. Of recent years, hardly any success has been met with in the direction of reducing its weight for a given energy-storage capacity, without detriment to endurance, and this weight is the great drawback of the storage battery in electric storage traction, and has been the principal obstacle to its advance in this direction for the past twenty years."—*The New Edison Storage Battery:* ARTHUR E. KENNELLY

Secondary cells or accumulators. THE fact that E.M.F.s are set up, during every electrolytic decomposition, in a direction counter or opposed to that of the electrolyzing current, has been referred to in the preceding chapter. This electro-motive force is called the E.M.F. of polarization. In all electrolytic cells, no matter what may be the character of the electrolyte that is decomposed, the cell itself, on the cessation of the electrolyzing current, will be able to produce a current in the opposite direction to that which produced the electrolysis. Cells produced in this way are called secondary cells or accumulators. They are also sometimes called storage cells or batteries.

Gautherot's observation of a secondary cell. The general fact on which all storage batteries are based was first observed in 1801, shortly after the invention of the voltaic cell, by a Frenchman

named Gautherot, who noticed that the silver or platinum wires that had been employed for decomposing water by the battery, especially when the water contained salt in solution, possessed the power of giving an electric current for a short time after being completely disconnected from the battery itself.

In 1803, Ritter made the same discovery, and immediately applied it to the construction of a secondary battery. This battery consisted of a series of pieces of gold, separated by cloth disks moistened by a saline solution. On sending a current from a powerful voltaic battery through this pile, it was capable, after being disconnected from the battery, of giving, for a short time, a current in the opposite direction to that of the current which had caused its action. Ritter formed a variety of secondary polarization batteries, employing for this purpose various metals, such as platinum, copper, iron, and bismuth.

Ritter's secondary battery of 1803.

In 1860, Gaston Planté greatly improved the secondary battery of Ritter by employing two plates of sheet lead, wound in the spiral form shown in Fig. 13, the two sheets being separated from one another by suitable means. On immersing these plates in dilute sulphuric acid contained in the glass jar, as shown, and passing an electric current between them through the intervening liquid, a secondary or storage battery was produced, capable of furnishing a fairly powerful electric current for a long time. In order to do this, however, it is necessary to "form" the battery, that is, to send a charging current between the lead plates for a given time, and then to change or reverse the direction of the current passing between the plates. These reversals in the direction of the charging current are made only after fairly

Planté's storage cell of 1860.

How Planté's storage cell is "formed."

considerable intervals, the current being permitted to traverse the solution in one direction for a long time, and then made to pass in the opposite direction for an equal length of time.

Fig. 13.—Planté Storage Cell. Note the manner in which the two plates of lead are closely coiled so as to be near each other without touching at any point.

Planté's secondary battery.

Under the above circumstances, it is found that the surface of the lead plates is changed by the action of the current to a fairly considerable depth, the plate connected with the anode becoming covered with a layer of lead peroxide, and the plate connected with the kathode with a layer of spongy, finely divided metallic lead. A secondary battery so formed will remain for a long time in this condition, and yet will be able to furnish current when the terminals are connected outside the battery by a conductor. Cells of this character will furnish an E.M.F. that varies from 2.2 to 1.85 volts. A number of separate storage cells may, as in the case of the voltaic cell, be connected in series or in parallel to form a single electric source called a storage battery.

It must not be supposed that the storage cell or battery stores electricity. This is no more true than that the spring of a clock, or of a music box, can be said to store time or musical sounds. What the spring really stores is muscular energy, that is, it renders it possible to put the muscular energy in such a form that it can, when so desired, be able to perform work and produce either a means of estimating time, or the production of musical sounds. In the same way, the so-called storage battery is an arrangement by means of which the energy of an electric current is caused to liberate, through the agency of electrolytic decompositions, such chemical substances as will be able to produce an independent electric current on the removal of the electrolyzing current.

No storage of electricity in storage battery.

Faure, in France, and Brush, in America, about 1881, so modified Planté's process as to greatly decrease the amount of time required for forming the battery. This was accomplished by giving the two lead plates a coating or covering of red lead, and then subjecting them to the forming process by passing the current between them when immersed in a solution of sulphuric acid in water. Under these circumstances, the plate connected with the anode was more highly oxidized into lead peroxide, and the plate connected with the kathode became covered with a layer of spongy lead.

Faure and Brush's improvement in storage battery plates.

In order to more carefully consider the actions that take place in the ordinary Planté cell, let us suppose two plates of lead, A and B, Fig. 14, to be placed in a dilute solution of sulphuric acid and water, and that a charging source, in the shape of a dynamo-electric machine, be connected as shown, the positive terminal to A, and the negative terminal to

Actions which occur on charging a Planté storage cell.

B. On the passage of the current between the plates in the direction indicated by the arrows, or from A to B, chemical decompositions will occur, which will result in the formation of lead peroxide, PbO_2, on the surface of the plate A, connected to the anode, and spongy or metallic lead on the surface of the plate B, connected to the kathode. On the termination of the charge, and the disconnection of the battery terminals of the cell, and the connection of the charged plate by conductors outside the liquid—in this case by a number of parallel or multiple con-

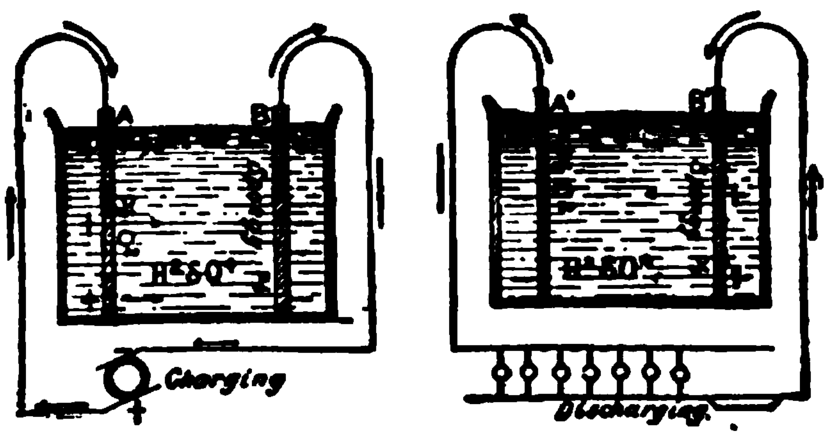


FIG. 14.—Charging and Discharging a Planté Storage Cell.

nected incandescent lamps, as shown on the right-hand side of the figure—a current will be produced which will flow through the liquid in the opposite direction to that of the charging current, or will pass from the plate that is covered with spongy lead to the plate covered with lead peroxide, that is, from B′ to A′.

The result of this discharging current is to cause some of the lead peroxide on the plate A′ to give up one atom of its oxygen to the metallic lead that covers the surface of B′, thus leaving both plates covered with PbO. As soon as this occurs, the cell becomes inactive, or is no longer able to furnish current without being recharged. In actual practice it is found best not to continue to discharge the cell as far as this point.

For the sake of simplicity we have described the above process as consisting of the formation of lead peroxide and metallic lead, and the decomposition as consisting in one atom of oxygen leaving the lead peroxide and combining with the metallic lead on the opposite plate. As a fact, however, this is only the final result of a series of actions that are too complex to discuss at length in this book.

Real action in charging and discharging more complex than that above described.

The life of a storage battery, or its ability to continue to furnish electric currents, depends on a variety of circumstances. So far as the actions above considered are concerned, there are no reasons why storage batteries should not continue almost indefinitely to act as sources of current, provided they are recharged at proper intervals. In actual practice, however, circumstances occur which render the cell valueless after a certain length of time. Of the great difficulties that arise in practice, one is due to the tendency of the coatings of peroxide and metallic lead to separate themselves from the surfaces of the plates, thus lessening the amount of current the cell is able to produce. Or these coatings become partly separated, and thus greatly increase the resistance of the cell, and, therefore, lessen its output. Again, the differences of expansion between the lead and the coatings on its surface cause the plates to buckle, and thus become detached. Notwithstanding these difficulties, however, storage batteries can be made to continue in efficient service for many years.

Circumstances affecting life of storage battery.

Buckling of plates.

For the purpose of ensuring a better adhesion of the active material to the surface of the lead plates, as well as for the purpose of increasing the extent of their surfaces, the lead plates are roughened, or, what is still better, are made in the shape of grids; *i.e.*, of various forms of open network, or plates con-

Use of grids or supporting plates.

taining numerous perforations. The active material is formed or placed within these perforations. The length of life of the storage battery during which it can be commercially employed can also be increased by avoiding too rapid a discharge of the cell, and also by avoiding discharging the cells too far, and taking care to recharge them frequently. It is also advisable to maintain the density of the sulphuric acid and water within certain fixed limits.

Lead-antimony grids.

In order to prevent the decomposition of the lead support or grid during the act of charging, the lead of which it is formed is generally alloyed with a small quantity of antimony.

Planté form of storage battery.

Faure type of storage batteries.

Various forms have been given to the storage batteries now in general use. These forms can, for the greater part, be broadly divided into two classes; viz., those of the Planté type, in which there is no salt of lead placed on the support or grid, but the active material is formed out of the substances of the lead plate by the act of the charging current, and those of the Faure type, in which such active materials are placed either directly or indirectly on the grids.

Gould storage battery.

An example of the first class may be found in the "Gould" plates. Here the grids or supports consist of lead alloyed with cadmium, in place of the antimony usually employed. On these grids are placed a number of separate sections, which are prepared as follows: Blocks of dense, rolled sheet lead, as pure as can be obtained, have their surfaces cut or spun into a great number of parallel ridges or grooves. This is accomplished by placing the blocks in steel frames between two rapidly revolving shafts, on which are mounted alternate steel disks separated

by spacing washers. The knives are so arranged that they merely cut into, but do not remove any of the lead. The disks or knives, as they cut into the lead, merely displace the lead and spin it in the form of ribs in the spaces between the knives. The number of sections that are mounted on each grid depends on the character of the cell, and on the polarity of the plate, the positive plate having, as a rule, twice as many sections as the negative plate.

It is claimed that the above method, of mechanically dividing the superficial area, increases this area to from 10 to 20 times its original value, thus giving

FIG. 15.—Gould Storage Battery Plates.

from 200 to 400 square inches of surface per pound of lead, and providing, at the normal rate of discharge, some 250 inches of conducting surface per ampère of discharge. The plates are formed as in the original Planté process, by placing them in a dilute solution of sulphuric acid, and passing the current between them. The general appearance of a positive and negative plate is shown in Fig. 15. Here it is claimed that, with a superficial area of only 480 square inches, there is provided a contact area of 4,800 square inches.

Method employed for mechanically increasing the area of the plates.

Storage battery, "chloride" type.

Probably by far the greater number of storage batteries now in every-day use are of the "chloride" type, as made by the Electric Storage Battery Company. Here the plates consist of lead-antimony grids, containing a number of buttons of lead peroxide and metallic lead, supported on the negative and positive grids respectively. As generally arranged, a number of separate positive plates are connected together in parallel, to form a single positive plate,

Fig. 16.—Chloride Type of Storage Cell, Electric Storage Battery Company. Note the positions of the terminals A and B, and the small buttons, etc., of active material placed in the lead-antimony grids.

and a number of negative plates similarly connected to form a single negative plate. A battery of this type is represented in Fig. 16, where the multiple-connected positive and negative plates are connected as shown to a common positive and negative terminal. The cell here represented can furnish a discharge of 25 ampères for 8 hours, 35 ampères for

4 hours, 50 ampères for 3 hours, and 100 ampères for 1 hour. It weighs, when filled with acid and ready for use, 136 pounds, of which 40 pounds consists of the charge of acid. The cell is 16 inches in height.

Series-connected storage cells.

Where it is desired to obtain a higher E.M.F. than can be supplied by a single cell, a number of separate cells are connected in series. In this case, the positive and negative plates of contiguous cells are connected together in the manner shown in Fig. 17.

FIG. 17.—Series-connected Storage Cells, "Chloride" Type. Here the three separate cells are connected in series, thus increasing the E.M.F. of the storage battery.

Storage battery for driving motors of automobiles.

Storage batteries are now generally employed for driving the motors of automobiles. In such cases, the connections of the various cells will, of course, depend on the amount and pressure of the driving current that is desired. A storage battery, suitable for such use, is shown in Fig. 18. The battery here represented is capable of supplying 17 ampères for 3 hours. It weighs, when complete, only 18¼ pounds, and has a height of 11½ inches.

In the Edison storage cell, the positive and nega-

tive plates consist of active material placed inside perforated metallic grids. These grids, however, instead of being formed of lead, are made of plates

Fig. 18.—Chloride Storage Battery or Accumulator for Automobiles. Note the compact form of the battery.

Edison nickel-iron storage battery

of punched steel. The positive and negative grids are alike, the difference being obtained by a difference in the character of the active material that is

Fig. 19.—Nickel-steel Grid for Positive or Negative Plate of Edison Nickel-iron Storage Battery.

placed in the perforations. The electrolyte employed consists of an aqueous solution of caustic potash. The shape of the grids is represented in Fig. 19,

TELEPHONE "CENTRAL" FOR CHINATOWN

San Francisco's Chinatown boasts a telephone exchange all its own, where pig-tailed operators, under the protection of a "Joss," answer calls in business-like fashion. The versatile wire transmits equally well messages in English and Chinese

where, as will be seen, there are a number of rectangular openings, shaped like the panes or lights of glass in an ordinary window, there being 24 of these perforations in the grid represented in the figure.

The iron and steel grids so formed are filled with two different kinds of active material, which consists respectively of a finely divided salt of nickel, and a finely divided salt of iron. In each case these salts are mixed with an equal volume of finely divided flaked graphite, merely for purposes of decreasing their electric resistance. They are then solidified into briquets by pressure, and are placed inside of metallic boxes, formed of thin plates of perforated nickel steel of such size that they can be forced by heavy hydraulic pressure into the rectangular openings of the grids. In this way, there are obtained plates that, when placed in the electrolyte of potash, and subjected to the action of the charging current, are converted into a hyperoxide of nickel, that is, an oxide higher than the peroxide, and into spongy metallic iron. After the discharge the grids are covered with peroxide, that is, a lower oxide of nickel, and oxide of iron. A number of separate positive and negative plates are connected together in multiple arc, as in the ordinary lead storage battery.

Positive and negative plates of Edison's storage battery.

The Edison storage cell produces a voltage of 1.5 volts, and maintains a mean voltage of 1.1 volts during the discharge. The great advantage claimed for the Edison storage battery lies in the fact that its weight is far less than that of the ordinary lead battery, thus rendering it far better suited for the driving of automobiles. In the ordinary lead storage batteries, the weight of the solution is equal to about 44 per cent of the weight of the active material, or

Some advantages of Edison's storage battery.

about 25 per cent of the total weight of the cell. In the Edison cell, however, the weight of the solution is only some 20 per cent of the weight of the active material, and only 14 per cent of the total weight of the cell.

Precaution recommended for prolonging life of storage batteries.

The length of time it is possible for a storage battery to continue economically to supply current depends, as has already been pointed out, on the care that has been taken of it. When first received from the factory, the ordinary lead battery should be given a five hours' charge at the normal rate. If it has been shipped with the electrolyte, as is sometimes done when the distance is short, it should be charged at a lower rate for a proportionally greater length of time. Of course direct currents only can be employed in charging. In charging, great care must be taken to see that the positive pole of the charging source is connected with the positive wire of the battery, and the negative pole of the charging source with the negative wire. Otherwise, considerable damage may be caused. Great care, too, should be taken to maintain a constant level of the liquid in the cells. If the loss has been occasioned by evaporation, the liquid should be brought to its normal level by the addition of pure water, but if the loss has been occasioned by spilling, fresh acid solution should be added. In all cases, a constant density of the solution is maintained by the frequent use of a suitable hydrometer.

Circuit connections for charging storage cells.

Charging can be accomplished by means of current taken either from the mains that supply incandescent lamps with current, or from the trolley wires. The connections necessary for such charging are shown in Fig. 20. In the case of the "chloride" cells, there is marked on the battery the number of

incandescent lamps that should be connected in series or in parallel, as shown in the above figures.

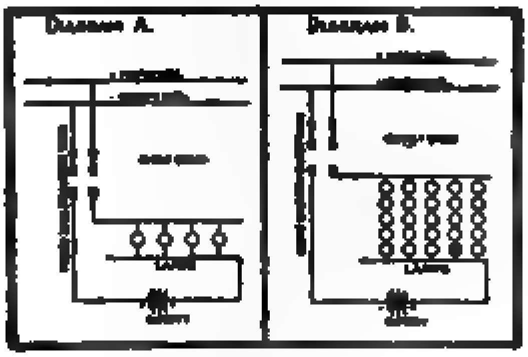


Fig. 20.—Circuit Connections for Charging Storage Cells for Lighting and Trolley Circuits.

Storage batteries can be applied to a great variety of purposes. Without enumerating all of these, it is interesting from a historical standpoint to note that, as early as 1872, Planté constructed a variety

Planté's incandescent lamp of 1872

Fig. 21.—Planté's Incandescent Platinum Lamp of 1872. Note the means employed for leading the electric current into and out of the incandescing filament.

of incandescent electric lamp, employing platinum wire for the incandescing filament. This lamp assumed the form shown in Fig. 21. It was formed

of a platinum wire of small diameter, that was rendered incandescent by the passage of the current from two of his secondary cells. Planté employed two of these lamps in dimly lighting a room where a number of scientific men had met for the discussion of some of the practical applications of the storage battery. Each of these lamps produced, for about an hour, a light of one candle-power.

Use of storage batteries for lighting of carriages and steam cars.

Storage batteries are seldom applied for the operation of incandescent lamps on any large scale, since, for such purposes, the currents produced by the various forms of dynamos or generators already described are far more economical. For purposes of isolated lighting, however, where primary batteries have previously been used—as, for example, in the lighting of the lamps of carriages, or the cars on ordinary steam roads—storage batteries have almost entirely replaced primary batteries. They are also much employed for the lighting of private country residences where the noise of a steam generating plant would be objectionable.

Some of the many uses to which storage batteries have been put.

In addition to the above, storage batteries have, to a great extent, replaced primary batteries for various kinds of dental, medical and surgical work; also for driving the motors of sewing machines, phonographs and kinetoscopes. They have been employed to some extent in various systems of fire alarms, and in some systems of telegraphic and telephonic communication. They are extensively employed for electric vehicles, electric launches and electric torpedoes. Although efforts have been made to apply them to the propulsion of street cars, yet, so far, the systems already in use have proved far more economical and convenient.

Perhaps one of the most important uses for which

storage batteries are employed is in central lighting and power stations. Here they are used to supplement the dynamos and generators in the supply of current during those intervals of the twenty-four hours of the day when an unusual demand is made on the output of the station. In the New York Edison Electric Lighting Company's sub-stations on Manhattan Island, a very large installation of storage batteries is employed. The standard bat-

Use of storage batteries in central stations.

FIG. 22.—Booster Set, Gould Company's Type. Note the principal function of a booster set when employed in connection with a storage battery, viz., to provide a voltage extra to that of line voltage so that the battery may charge.

teries used in these sub-stations contain 150 cells, each having a capacity of 4,000 ampère hours at a ten-hour rate of discharge. The batteries are charged from the bus-bars, by means of special generators, called boosters, that is, dynamos inserted in special feeders or groups of feeders for the purpose of raising their pressure above the other feeders, this increase of pressure being necessary in order to

charge the storage batteries. These batteries are charged during hours of light load. A booster set of the Gould Company's type is shown in Fig. 22. These dynamos are shunt-wound. An installation of a large storage battery, in connection with a booster set, is shown in Fig. 23.

Fig. 23.—Large Storage Battery in connection with a Booster Set.

Use of storage batteries on electric locomotives

Sometimes powerful storage batteries are installed on electric locomotives for the purpose of either reinforcing the regular current obtained on the trolley wire, or at times of operating the train independently of such current. Such an application has been made on the electric locomotives that are employed on the Baltimore & Ohio Railroad for hauling the trains and locomotives through the Baltimore tunnel.

Planté's researches in high E.M.F. discharges from series-connected storage cells.

Planté, by the use of a great number of separate secondary cells, connected in series to form a single battery, conducted a remarkable series of experiments on the luminous effects produced by the passage of high E.M.F. discharges through liquids. He employed, in some of these experiments, a series-

connected battery B, Fig. 24, consisting of twenty simple secondary cells, and connecting in series, as shown, with the galvanometer G, the voltameter V, containing a dilute solution of sulphuric acid and water, and the platinum wire F. When the positive wire was dipped in the liquid he noticed that as soon as the negative wire was plunged beneath the surface there was no liberation of gas, but a luminous sheath appeared around the wire, the positive wire setting free only a small quantity of gas. The galvanometer needle showed only a slight deviation, and the platinum wire F was but feebly heated, proving that only comparatively feeble currents were passing. In a few moments, however, as the E.M.F. of the

Luminous sheath surrounding negative wire.

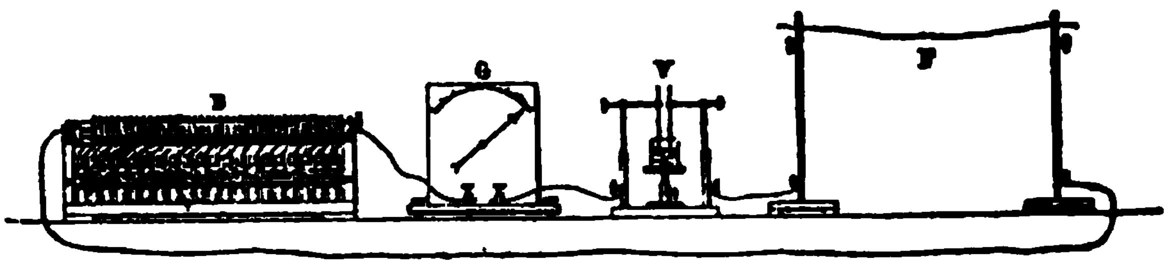


FIG. 24.—Phenomenon of the Luminous Sheath.

battery falls, the luminous sheath disappears, and an abundant evolution of gas occurs suddenly at both poles, the galvanometer needle showing a marked deflection and the platinum wire becoming heated to incandescence throughout its entire length. The color of the light is at first white, and then passes successively to blue and violet, and toward the last, a few seconds before the passage of the strong current, changes to a reddish purple.

Varying colors of luminous sheath.

In order to study the effects produced by increasing the E.M.F., Planté employed a great number of cells, adopting the expedient of charging these cells, when connected in parallel, by the current produced from two to four Bunsen cells. He afterward connected the storage cells in series, the change from the series to the parallel connection being obtained by

Planté's method of charging his batteries of storage cells.

the use of a suitable commutator. By these means he could expend, at will, in a few moments, all the energy that had accumulated during several hours.

Series-connected battery of 800 storage cells.

In the powerful secondary battery, shown in Fig. 25, there are 400 secondary cells, divided into ten batteries of 40 cells each. When so desired, another battery of the same size, in an adjoining room, could be connected with this battery by suitable wires, thus placing at his disposal a discharge from 800 cells. Although such E.M.F.'s would not be excessive as

FIG. 25.—Powerful Series-connected Battery of 400 Storage Cells. Note the powerful discharge that is obtained by the discharge of these storage batteries in a few minutes.

compared with E.M.F.'s that can be produced to-day by other means, yet, owing to the small resistance of the storage cells, the momentary currents produced must have been of very great strength.

Phenomena produced on surface of liquids by use of 200 cells.

When a battery of 200 cells was connected with the glass vessels containing liquids, shown in Fig. 26, one of which contained sulphuric acid and the others a solution of common salt and water, some curious phenomena were observed. When, as in the case of the vessel on the extreme left-hand side of

the figure, the positive terminal was first immersed below the surface of the acidified water, on the approach of the negative terminal toward the surface of the liquid a fusion of the negative wire, or its vaporization, was produced, accompanied by a slight explosion and a flame that varied in color, according to the metal employed for the conducting wire. By employing a smaller quantity of acid in the water, so as to thus increase its resistance, the approach of the negative wire was accompanied by a continuous series of sparks that were attended by a crackling noise. These continued for a few moments, until the E.M.F. of the battery was reduced.

FIG. 26.—Luminous Liquid Globules, produced by 200 Cells.

Luminous liquid globules.

When the negative terminal of the battery was immersed below the surface of the liquid, as in the case of the two remaining cells, which in this case contained a solution of common salt, the approach of the positive terminal produced a different character of result. The wire was not melted, but a small luminous liquid globule was formed, accompanied by a curious noise. As the wire was gradually withdrawn from the liquid, the globule increased in size, as is represented at the right-hand side of the figure, taking on a rapid rotary motion, and flattening as a result of this motion. But what is most curious, as we are assured by M. Planté, was that the direction

of this rotation was not constant, as would have been the case had it been caused by electro-magnetic whirlings, but that it sometimes moved in one direction and sometimes in the opposite.

Wonderful phenomenon of the wandering electric spark.

A still more curious phenomenon was that produced when the terminals of the secondary battery of 800 cells were placed in connection with the coatings of a condenser. This condenser consisted of a sheet of mica, on the opposite faces of which were placed coatings of tin-foil. When these coatings were connected with the terminals of the battery, the condenser was charged in a manner similar to the Leyden jar. If, however, by chance a weak spot existed in any part of the mica, and the opposite charges pierced the dielectric, in place of there being an instantaneous discharge between the two coatings, a fusion both of the metal and of the dielectric occurred, and an incandescent, brilliant, luminous globule moved slowly and with a peculiar noise over the surface of the metallic coating, tracing an irregular, sinuous line on the metal. The shape of this track is that represented in Fig. 27, as accurately reproduced from a tracing made by the wandering globule in one of Planté's experiments. The positions successively assumed by the globule are represented at A, B, C, D, E, etc., in the regular order of the letters of the alphabet.

Planté's theory of ball or globular lightning.

In view of the above and some other experiments he made in wandering sparks, Planté formed a theory for the phenomena of globular or ball lightning. He suggested that such balls are due to the passage of high tension discharges between the two coatings of a Leyden jar, consisting respectively of the earth and the upper regions of the atmosphere, such discharges passing from one coating to the other through ascending columns of moist air. We

have already, in Vol. I, suggested that to this explanation should be added the possible action of the actual decomposition of some of the so-called chemical elements into the state that is represented by split atoms or electrons.

Fig. 27.—Phenomena of the Wandering Electric Spark. Note the extremely irregular path taken by the wandering electric spark.

Planté's suggestion as to the possible cause of sun-spots.

If a sheet of filter paper, moistened by salt water, be connected with the negative terminal of a secondary battery of 400 elements, and the positive terminal be touched to any part of the positive surface, a flash of light is produced, together with a rapid evolution of vapor, so that a crater-shaped cavity will be formed, having the appearance represented in Fig. 28. Planté points out the resemblance between this crater-shaped opening and the spots observed in the photosphere of the sun, and suggests the possible electric origin of these spots.

Electro-static engraving.

Observing that, when a luminous spark was formed against the sides of a glass vessel, the walls of the glass were deeply corroded, Planté conceived

FIG. 28.—Crater-like Perforations Produced by High E.M.F. and Current Discharges. Note the similarity of these perforations to the general appearance of a sun-spot.

the idea of engraving on glass by high-potential electric discharges. He did this in the manner shown in Fig. 29, where the negative terminal of a battery of from 50 to 60 elements is moved over the surface of a glass plate that is covered with a saline solution, preferably nitrate of potash, the positive termi-

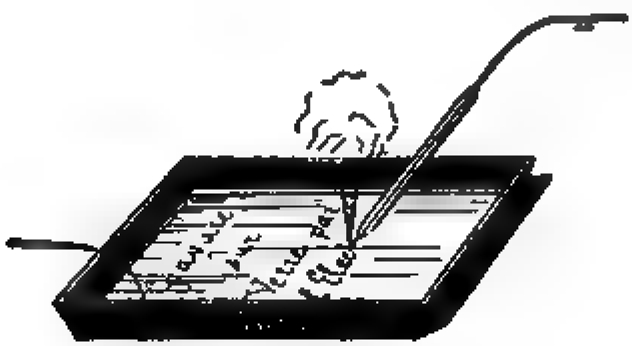


FIG. 29.—Planté's Method of Engraving on Glass by High-potential Electric Discharges.

nal having been previously placed in the solution. Under these circumstances, a luminous spark appears wherever the negative electrode approaches the glass. This spark permanently corrodes the glass or engraves its movements on its surface, causing, in this particular case, the words "Engraving on glass by electricity."

CHAPTER V

ELECTRIC FURNACES AND SOME MISCELLANEOUS APPLICATIONS OF ELECTRO-CHEMISTRY

"The future can take care of itself. The artificial production of nitrate is clearly within view, and by its aid, the land devoted to wheat can be brought up to the 30 bushels per acre standard."—PROFESSOR CROOKES

BROADLY speaking, an electric furnace is a furnace in which electrically generated heat is employed either for effecting difficult fusions, for the extraction of metals from their ores, or for other metallurgical operations. In the electric furnace the heat is obtained either from electric incandescence, or from the voltaic arc. Where the voltaic arc is employed, the substances to be treated are either exposed directly to the arc, or are placed in its immediate neighborhood. The direct method has been employed in the case of some furnaces for treating ores where the crushed ores are permitted to slowly fall through the arc. In other furnaces, however, the ores or other substances to be treated are placed between electrodes, the current being passed through them after they have been fused either by an ordinary furnace, or by heat of electric origin. Electric furnaces may, therefore, be divided into two general classes; viz., resistance furnaces, where the materials are heated by their own resistance, and arc furnaces, where they are heated either directly by the voltaic arc, or by being placed in its neighborhood. In other words, arc furnaces may be divided into direct-arc furnaces and reflect-

Electric furnace defined.

Two classes of electric furnaces.

Resistance furnaces and arc furnaces.

ing-arc furnaces, in which the heat is thrown on the charge by reflection from suitable surfaces. To the above may be added the additional class of furnaces in which an electrolytic separation is obtained, by passing the current through the materials after they have been fused by the action of heat however obtained.

Direct arc-furnaces and reflecting-arc furnaces.

In cases where the reduction is carried on by mixing crushed ores with suitable fluxes and with carbon, the heat may be obtained by the action of either alternating or direct currents. Where electrolytic decompositions are effected, direct currents only can be employed. In some cases, where alternating currents are employed, it is, as yet, uncertain whether the furnace actions are obtained by the action of heat alone, or by electrolytic decomposition. In most operations, however, heat is probably the sole cause of the reactions.

Direct-current electric furnaces and alternating-current furnaces.

Although electric furnaces have only come into extended practical use during the past few decades, yet they were known and operated on a small scale at a comparatively early date. This was only what was to be expected, since, as soon as scientific men became aware of the exceedingly high temperatures that could readily be obtained either by the voltaic arc, or by electric incandescence, they applied such sources of artificial heat to various furnace operations.

Electric furnaces known from early dates.

The pioneer in the construction of electric furnaces was Davy, whose brilliant discoveries of sodium, potassium, and other metals have already been referred to. In some of his experiments, in order to eliminate the effects of the atmosphere, he placed the fused potash on which he was operating in closed

Davy, the pioneer in the art of electric furnaces.

glass tubes, and led the decomposing current through the tube by means of platinum wires. In other experiments, he passed the current through potash while in a state of igneous fusion. Either of these processes may be regarded as having necessitated the use of a primitive electric furnace.

In 1815, Pepys demonstrated the identity in the chemical constitution of the diamond and carbon by employing an electric furnace of an exceedingly simple construction. He bent an iron wire in the shape of a V, and formed a deep cut in the middle of the bend by a file. Placing a small quantity of diamond dust in this cut, he raised the temperature of the iron to intense incandescence by the passage of an electric current. At the end of the operation he found that the diamond had united with the iron, and had changed it into steel.

Early electric furnace of Pepys.

In 1844, James Napier, of England, took out a patent for an electric furnace, in which the substances to be operated on were placed in a crucible of graphite, or other refractory material, that was a conductor of electricity. The crucible was lined, except at the bottom, with clay, or other refractory substance that was also a non-conductor of electricity. The calcined ore to be treated was subjected to the heat of an ordinary fire. When the temperature of fusion was reached, the mass was then subjected to the passage of an electric current, the terminals of the electric source being connected respectively with the crucible and with the molten material placed inside of it.

Napier's electric furnace of 1844.

In 1849, Despretz, a member of the French Academy of Sciences, constructed electric furnaces with which he conducted an extended series of experi-

Despretz's electric furnace.

ments on the fusion and volatilization of various substances. In a paper read before the Academy, December 17, 1849, Despretz announced, as he then believed, that he had succeeded in fusing carbon. It was during these experiments that Despretz noticed that, at the high temperatures at which he was operating, a part of the carbon was converted into graphite. The electric current employed by Despretz in these furnaces was obtained from a battery consisting of 600 Bunsen cells. His experiments were made with carbon in various forms, such as anthracite and bituminous coal, graphite, and even the diamond. In fusing these substances, they were either exposed directly to the heat of the arc, or they were fashioned in the shape of slender rods, and rendered incandescent by the passage of the current through them.

Watt's electric furnace.

In 1851, Charles Watt, of England, invented an electric furnace designed for the electrolytic decomposition of metallic salts of such metals as are readily volatilizable at high temperatures. Watt applied this furnace to the preparation of the metals of the alkalies. The salt to be electrolyzed was first fused by the heat of an ordinary furnace, and the decomposing current sent through the fused mass. A hood was placed over the kathode for the collection of the vapor of the metals that was liberated at this point.

Watson and Prosser's electric furnace.

In 1853, Watson and Prosser invented an electric furnace designed for use in "An improved method of manufacturing steel and of carburizing iron." It may be mentioned, in this connection, that the broad idea of employing electric currents for improving cast-iron, or converting it into steel, appears to have occurred to many metallurgists. Among some of those who proposed to make such use of electric

currents may be mentioned Wall, in 1843; Holmes, in 1856; Dawes, in 1867; Monckton, in 1869; and Motier, in 1871. It is interesting, in this connection, to note that the Holmes above referred to, was the Holmes whose dynamo-electric machine was used at an early date in an English lighthouse.

Some early inventors of electric furnaces for the production of iron and steel.

In 1873, Werdermann, to whom we have already referred in connection with the invention of the semi-incandescent electric lamp, invented a form of electric furnace in which he employed the current obtained from a dynamo-electric machine. In Werdermann's furnace, the ore to be heated was first crushed, mixed with the proper flux, and brought to the heat of fusion by means of an ordinary furnace, and was then subjected to the action of the current passed through the molten mass.

Werdermann's electric furnace.

FIG. 30.—Siemens's Electric Furnace.

Charles William Siemens invented an electric furnace in 1879. One form of this furnace is represented in Fig. 30. It consists of a means for obtaining an intense heat by forming a voltaic arc inside of a crucible of a refractory material. The terminals A and B are formed, A of carbon, and B

Siemens's electric furnace.

of some metallic substance cooled by the circulation of water. In order to avoid the tendency of the voltaic arc to pass to the walls of the crucible, that is made of graphite, the inventor adopted the expedient of surrounding the outside of the crucible with a coil of wire. In order to give some idea of the operation of this electric furnace, the following results obtained by its use are given by Huntington in a paper read before the British Association for the Advancement of Science, in August, 1882.

Huntington on Siemens's electric furnace.

"The current employed, which was of from 250 to 300 ampères, was obtained from five dynamo-electric machines, four of which were coupled together, and the other was employed as an exciter.

"A number of difficult fusions were effected, viz.:

"(1) Six pounds of wrought iron were kept in the heat of the arc for twenty minutes and then poured into a mold. The cooled metal was found to be crystalline and to no longer possess the ability to be wrought.

Some metallurgical work done by an early electric furnace.

"(2) Twenty pounds of steel were completely melted in one hour in a single charge.

"(3) Three-fourths of a pound of copper, placed in carbon dust, was melted in half an hour—only three-fourths of an ounce, however, was found remaining in the retort. The rest had been vaporized.

"(4) One-quarter of an hour was sufficient to reduce eight pounds of platinum to the liquid state.

"(5) Some curious results were noticed both during the fusion and vaporization of tungsten, and in the properties of the product as found in the electric crucible."

The electric furnaces before referred to afford admirable instances of inventions born before the times were ripe for them. Although many of the furnaces already described are capable, with trifling

modifications, of being applied to regular work, yet they failed mainly because of the very large electric currents required for their commercial use. When, however, cheap currents produced on a large scale, as at Niagara Falls, made it possible to supply enormous currents at low rates, manufactures, based either on the use of electric furnaces, or of electrochemical processes generally, rapidly multiplied, until they have to-day reached to such proportions that, at Niagara Falls, some 45,000 horse-power is employed in some 20 electric processes for reducing the metals or producing chemical compounds.

Why early electric furnaces were commercially unsuccessful.

Coming now to the electric furnaces actually employed to-day, we find that they are mainly of the incandescent and the direct-arc heating types. What principally serves to distinguish them from the electric processes employed in the early history of the art, is the enormous currents they employ. The modern electric furnace consists practically of a heat-tight chamber, lined with some highly refractory substance, generally blocks of carbon, and rendered nearly non-conducting, so far as heat is concerned, by some such refractory substance as magnesia or chalk forming the body of the furnace. By the aid of these furnaces it is possible to obtain a temperature not far below that of the boiling point, or point of vaporization of carbon.

Modern electric furnaces.

The advantage of the electric furnace lies largely in the ease with which its heat can be regulated by the regulation of the heating current. Under the exceedingly high temperatures so obtained, temperatures, moreover, that are readily maintained for practically any length of time, chemical substances are formed that would have been otherwise unknown, since, at the high temperatures employed,

Advantages of modern electric furnaces.

chemical reactions take place that would be impossible at lower temperatures. It will be interesting, therefore, to call attention to some of the practical applications of modern electric furnaces.

Acheson and the manufacture of carborundum.

One of the earliest of such products is a material called carborundum, a carbide of silicon, which was obtained by Acheson in 1893. This substance is now generally employed as an abrasive for cutting and polishing hard substances, being well suited for such purposes, since it is almost as hard as the diamond. It is manufactured as follows: Granular coke is placed in the form of a conducting core in the centre of the longitudinal furnace shown in Fig.

FIG. 31.—Manufacture of Carborundum—Acheson's Process.

31, directly between a series of carbon rods, that are connected with the terminals of some powerful source of electricity. This core is surrounded by a mixture of carbon, sand, sawdust, and common table salt. The furnace is closed, and an electric current passed through the core so as to render it highly incandescent. Under the prolonged influence of the heat, a combination occurs between the carbon, mainly of the core, and partly of the surrounding carbon, with the silicon of the sand, a carbide of silicon, or carborundum resulting. The scale on which this manufacture of carborundum is carried on may be judged from the fact that ten furnaces are employed, the fire-brick bed of each furnace being 16 feet long and 5 feet wide, and the furnace

being 2 feet thick and 8 feet high. The general appearance of such a furnace is shown in Fig. 32.

Use of alternating currents in carborundum furnace.

Alternating electric currents are employed for heating the furnace charges, the electric pressure being reduced from the high pressure mains employed for carrying the current from the generators by

FIG. 32.—Carborundum Furnace, charged and ready for the passage of the exciting current through it.

means of a step-down transformer. By the use of a regulator, the voltage can be varied from 250 volts at starting to 185 volts after the core and furnace have become thoroughly heated, thus giving a current at starting of 2,000 ampères, and a current of 8,000 ampères when the furnace has become heated. Each furnace takes a charge of about 1,000

lb. of core matter, and, after a run of some 36 hours, produces from 3 to 4 tons of carborundum. After

Uses of carborundum.

a complete run, the furnace is allowed slowly to cool for several hours, and is then gradually uncovered. Besides its use as an abrasive, carborundum has been employed to add to steel, in order to ensure sound castings, it being possible to introduce silicon in this manner into the steel without the danger of contaminating it with sulphur or phosphorus.

Another valuable product of the electric furnace is calcium carbide. This is produced by subjecting

FIG. 33.—Electric Furnace for the Manufacture of Calcium Carbide.

a mixture of lime and carbon to the prolonged action of a voltaic arc. Various forms are given to

Furnace for the manufacture of calcium carbide.

such furnaces, one of which is shown in Fig. 33. Here B consists of a crucible of carbon or graphite, which is attached to one of the terminals of the dynamo D. The other terminal of the dynamo is connected with a large carbon electrode, C, that can be moved toward or from the charge by a screw threaded shaft *g*, under the action of *h*. The mixture of lime and carbon is placed at the bottom of

the furnace, at *e*, and an arc, produced by means of an alternating current of 5,000 ampères, at a pressure of 25 volts, is caused to act directly on the charge. A tap hole at *d* is provided for running off the material from time to time. Calcium carbide is produced in large quantities, most of which is employed for the manufacture of acetylene gas, employed for producing a brilliant light when burned in air. The gas is liberated from the calcium carbide by merely throwing the carbide in water.

Principal use of calcium carbide.

The production of calcium carbide by the electric furnace leads all other of the electro-chemical industries, so far as the amount and value of the product are concerned. It is estimated that no less than 250,000 horse-power of electric current is employed in different parts of the world for producing this substance. The total annual output is about 300,000 tons per year, of which fully 1-5 is made in America. At the Union Carbide Works, at Niagara Falls, where carbide is made, the entire output of one 5,000 horse-power dynamo is employed for this purpose.

Enormous production of calcium carbide.

Another valuable product of the modern electric furnace is graphite. This is now produced in large quantities by the International Acheson Graphite Company, at Niagara Falls. As we have already pointed out, it was long known that the effect of the prolonged action of heat on carbon was to convert it into graphite. Mr. Acheson, under whose process graphite is now being produced artificially, observed that, at the centre of the core employed in his furnace for the production of carborundum, a mass of graphite was formed. In order to obtain a good output of carborundum, it is necessary to maintain a certain adjustment between the currents

Electric furnaces for the production of graphite artificially.

passing through the furnace at different times during the process; and this depends on the resistance of the core. A careful study of the conditions necessary to obtain this adjustment led Mr. Acheson to devise the process now employed for the production of graphite artificially. His process is based on the fact that metallic carbides, when decomposed, invariably produce graphite. The process is said to be based on three United States patents, one of which is for the production of pure arc-light carbons, by subjecting impure carbons for a long time to the heat sufficient to volatilize the impurities. Another patent is for the general principle of obtaining graphite artificially by the decomposition of metallic carbides, and hence, consists of first converting carbon into graphite by mixing it with some substance that is capable of converting it into a metallic carbide, and afterward into graphite by decomposing such carbide. The third patent is for the use, for this conversion into graphite, of such natural carbonaceous materials as contain, uniformly mixed throughout their mass, such metallic oxides as are capable of forming carbides, and afterward, graphite. In view of the prior state of the art, it would seem more than probable that many difficulties may arise in broadly sustaining these patents.

Principle on which the Acheson graphite process is based.

The process is very successful. Two classes of products are obtained; viz., graphitized molded articles of artificially produced graphite, in which the conversion is obtained by subjecting molded articles to the passage of the current while so stacked in the furnace that the principal heat produced by the passage of the current shall be limited to the articles themselves. The heating of the furnace begins at a pressure of 220 volts, with 3,000 ampères of current; these values are gradually changed, as the

Method of graphitizing molded articles of artificial carbon.

AN ELECTRICAL AID FOR THE DEAF

The "Acousticon," a device of M. R. Hutchison's, consisting of a small rubber disk receiver, an earpiece, and a tiny electric battery. The receiver, attached to the clothing, collects the sound, which the earpiece intensifies

furnace becomes heated, to a pressure of 80 volts, with 9,000 ampères of current. Twenty hours are required to convert the charge into graphite. Articles so converted are largely employed as electrodes in various electrolytic processes.

Another process carried on at the same works consists in the conversion of carbon in bulk into graphite. Carbon is employed in some such form as coal, throughout the mass of which a small quantity of finely divided metallic impurities in the shape of oxides of iron, are uniformly distributed. Such coal is often found in clean-washed, pea or buckwheat, anthracite coal. The heat necessary for the conversion is obtained by placing the coal in the furnace around a core of granular carbon that has been partially converted into graphite. The furnace, in which this operation is carried on, is lined with blocks of carborundum, a substance that has been found to possess very high refractory powers. A furnace requires about 20 hours to convert the material into graphite.

Method of graphitizing carbon in bulk.

Carborundum as a furnace lining.

The extent of the actual manufactures, based on the above processes, may be obtained from the fact that, according to the United States Census report, the product of graphite at this one plant at Niagara Falls reached, in 1900, a total of 1,400,000 lb.

Large output of carbon artificially graphitized.

Another exceedingly valuable application of the electro-chemical processes employed at Niagara Falls is for the production of metallic aluminium. This is accomplished by several processes, conducted on so large a scale that, according to the United States Census report, the amount produced in this country during 1899 was 6,500,000 lb., the total value of the product being $2,112,500. Metallic

Electrolytic production of metallic aluminium.

aluminium is produced at Niagara Falls by the Pittsburg Reduction Company at two works, one of which is situated on the grounds of the Niagara Falls Power Company, and the other at the edge of the gorge below the falls. These works employ more than 10,500 horse-power. The process is an electrolytic one. Consequently, the alternating currents furnished by the Niagara Falls Power Company must first be converted into direct current. This is done by taking the alternating currents received from the transmission wires at a pressure of 2,250 volts, and passing them through step-down transformers, by which they are reduced in pressure to 115 volts, and then converting them into direct current, at a pressure of 160 volts, by means of rotary converters.

Use of rotary converters.

The reduction is effected by passing the current through a number of reducing pots, containing baths of fused cryolite, to which aluminium oxide has been added. The energy of the current is expended both in reducing the materials in the reducing pots or electrolytic cells, and in keeping the charge in a molten condition. Metallic aluminium is drawn from the furnace at regular intervals and fresh oxide added, the process being a continuous one.

Electrolytic aluminium process.

Another valuable electro-chemical process, also established at Niagara Falls, is the electrolytic process for the production of caustic alkali and bleaching salts. This manufacture is carried on by the Castner Electrolytic Alkali Company, under a process patented by Mr. Castner in 1894. In this process, the electrolytic cell consists of a slate box, 4 feet long, 4 feet wide and 6 inches deep, divided into three compartments, by means of two partitions,

Castner Electrolytic Alkali Company

under each of which are grooves. These partitions extend to within 1-16 of an inch from the bottom of the cell. The three compartments are made independent of one another by means of a layer of mercury that extends up against the lower part of the partition. The central compartment is kept filled with pure water, and the remaining two compartments on each side are filled with a solution of brine, or chloride of sodium, from the electrolysis of which the metallic sodium is obtained. The two brine compartments are provided with numerous anodes of graphitized carbon, extending through the sides of the tanks to within about an inch of the surface of the mercury. On the passage of the current through the brine solution, electrolytic decomposition occurs, metallic sodium being liberated at the mercury kathode, with which it immediately combines, and the chlorine gas passing off at the carbon anodes through rubber tubes connected with the tops of gas-tight covers placed on the cells. This chlorine is employed in the manufacture of bleaching salts. By automatically and continuously tilting the cell from one side to the other, the automatic circulation of the mercury between the charging and the discharging compartments is ensured. The water is decomposed by the sodium alloyed with the mercury in the central cell, while sheets of iron, connected as a kathode, serve to liberate the hydrogen given off from the caustic soda of the solution. The solution of caustic soda is evaporated to solid caustic soda. Each cell requires 630 ampères of current at 4.3 volts.

Formation of solid caustic soda and bleaching powder.

Metallic sodium is produced by the Niagara Electro-Chemical Company, at Niagara Falls, by the electrolysis of a fused caustic soda, carefully maintained at a temperature but very little above its melt-

ing point. On the decomposition of the fused mass by the passage of the current, sodium and hydrogen appear together at the kathode, and oxygen at the anode. In order to prevent the reoxidation of the sodium and hydrogen with dangerous explosions, a gauze or screen is placed around the kathode, the meshes of which are sufficiently large to permit the circulation of the electrolyte, but not large enough to permit bubbles of hydrogen with globules of sodium to pass.

Electrolytic production of metallic sodium.

Another electro-chemical product produced at Niagara Falls is an artificial corundum, obtained by fusing bauxite and hydrate of alumina, and then permitting it to slowly cool. The product, which possesses the hardness of corundum and the toughness of emery, is employed in the arts as an abrasive.

Artificial corundum.

Still another electro-chemical product produced at Niagara Falls consists of soluble salts of barium, that are manufactured from the insoluble sulphate of barium, in an electric furnace, by fusing a mixture of barium sulphate and small quantities of carbon. Barium hydrate, the principal product, is employed in the manufacture of white paints, in sugar refining for recovering sugar from dilute solutions, and for the purpose of softening the water employed in steam boilers.

Manufacture of barium hydrate.

Another process has recently been established at Niagara Falls, which would appear to be of the greatest significance. It may, indeed, profoundly affect the world's industries, since it is a process for the production of nitric acid and such valuable fertilizers as sodium or calcium nitrate directly from the atmosphere. This process is based on the fact observed by Priestley, in 1785, as well as by Caven-

Nitric acid and fertilizers produced directly from the atmosphere

dish at a later date, that nitric acid may be directly formed by the union of the nitrogen and oxygen of the air by the passage of electric discharges through it. This process affords another of the many instances in which well-known processes can only be conducted on a commercial scale when electricity can be cheaply produced.

The process is thus described by Professor Chandler, of the Columbia University, of New York City:

Chandler on the fixation of atmospheric nitrogen.

"The apparatus consists of: A nitrifying chamber, which is a vertical cylinder provided with arrangements for maintaining a large number of electric arcs; a motor for causing the shaft in the nitrifier to rotate in order to produce the arcs; a motor-actuated blower for forcing a current of air through the nitrifier; a chamber in which the reaction between the gases is completed; an absorption tower which extracts from the air coming from the nitrifier and the chamber the oxides of nitrogen produced by the reaction, and a 10,000-volt dynamo driven by a 2,000-volt motor."

In the experiments which Dr. Chandler conducted he reports that:

"The absorption tower was thoroughly washed out and the dynamo was set in motion. A solution of caustic soda was allowed to trickle through the absorption tower, and the energy employed in producing the arcs was carefully measured.

"The experiment was continued for two hours, two and a half minutes, the energy consumed during this period being 12,500 watt hours, equivalent to 12.5 kilowatt hours.

"The product was carefully collected, measured, and analyzed, in order to ascertain the amount of nitric acid or its equivalent produced during the experiment.

"It was found that the product, which actually consisted of nitrate and nitrite of soda, contained the equivalent of one and one-quarter pounds of one hundred per cent nitric acid, equivalent to 1.785 pounds of seventy per cent nitric acid. (A common commercial strength of this acid.) Twelve and five-tenths kilowatt hours of energy produced, therefore, 1.785 pounds of seventy per cent acid. One kilowatt hour therefore produced 0.143 pounds. One kilowatt per year would therefore produce 1,253.5 pounds of seventy per cent acid. Assuming the cost of energy to be twenty dollars per year per kilowatt, the expense for energy would be a little less than 1.6 cents per pound of seventy per cent acid. The current price of this acid at the present time is five cents per pound.

Chandler's estimate of the cost of producing nitric acid electrically

"At the rate at which the acid was produced in this experiment, the yield of this unit of apparatus would be 8,766 pounds of seventy per cent acid per annum."

The nitrifying chamber employed in the above process is shown in Fig. 34. It consists of a cast-iron tank, in which a vertical iron shaft revolves 300 times per minute. On this shaft are placed 148 sets of wires tipped with platinum, which are caused by the centrifugal force to stand out horizontally, and so be brought near an equal number of similar platinum tipped wires that are connected with the sides of the tank. Each wire is furnished with an inductance coil, so that it may be able to form an independent electric arc or spark across the air gap between the two wires. The current employed to produce these arcs is furnished by a dynamo at a pressure of 10,000 volts. In front of each line of points is an air pocket, that collects the air as it is decomposed by the electric arcs, and leads it

Description of process.

through pipes to the absorption tower, where a shower of water takes up the acids that are formed. Besides the enormous importance of a process that is thus able to obtain an indefinite supply of a fertilizer so valuable in increasing the amount of the world's total wheat crop, the great number of pur-

Great significance of process.

FIG. 34.—Nitrifying Chamber Employed in the Fixation of Atmospheric Nitrogen.

poses for which nitric acid is employed in the arts, such as in the manufacture of high explosives, artificial coloring matters, the production of celluloid, etc., would seem to indicate that this branch of electro-chemical manufacture may soon become one of the world's leading industries.

Some other electro-chemical processes.

Many other valuable processes are employed both at Niagara Falls and elsewhere. Among these may be mentioned the production of phosphorus from natural phosphate rocks, the production of potassium chlorate from potassium chloride, the manufacture of camphor from turpentine, the manufacture of barium carbide and the cyanides by processes similar to those employed in the production of calcium carbide, the manufacture of ammonia, the direct production of oxides of lead from galena, and the manufacture of the silicides of calcium, barium, and strontium.

Silicide of carbon and hydrogen gas.

The silicide of calcium is a substance that, like carbide of calcium, possesses the power of liberating a fixed gas when thrown into water, only, in the case of silicide of calcium, hydrogen gas is liberated instead of acetylene. One pound of calcium silicide liberates 18.5 cubic feet of hydrogen. This is of especial importance, from the fact that it is possible thus to readily fill balloons with hydrogen gas. The silicide of barium is also said to possess the valuable property of removing sulphur and phosphorus from molten steel.

Still others.

To the preceding, there might be added the manufacture of sulphuric acid, but our limited space will prevent any further mention. What has already been given will amply suffice to show the great value of electro-chemistry in the practical arts.

In all the cases of electro-chemical decomposition just referred to, it has been necessary to use the direct electric current. When alternating electric currents are sent between two insoluble electrodes, through a solution capable of being electrolyzed, the electro-positive and electro-negative ions, that are alternately liberated at each electrode, re-

combine as fast as they are set free, so that no permanent decomposition can be observed. Under certain circumstances, however, these recombinations are not complete, so that some permanent decomposition results. This will be the case where the ions, liberated during the passage of the current in one direction, are capable of reacting on the solution to form insoluble compounds. Under these circumstances, the compound is removed from the influence of the electrode, and is no longer able to recombine with the other substances liberated.

When alternating electric currents can produce permanent electrolytic decomposition.

II

THE ELECTRIC TELEPHONE

CHAPTER VI

REIS, BELL, GRAY, AND DOLBEAR. THEIR CONNECTION WITH THE SPEAKING TELEPHONE

"Is there anything whereof it may be said, see this is new? It hath been already of old time, which was before us."
—*Eccl.* i. 10

THERE is, probably, not a single piece of electric apparatus that contains so many elements of the marvellous as does the articulating or speaking telephone. It is marvellous in the simplicity of its construction; it is marvellous in its operation, combining as it does a dynamo-electric generator driven by the voice of the speaker, and an electro-magnetic motor that acts so as to exactly reproduce the spoken words, and all this with apparatus of the simplest type; finally it is marvellous in the simplicity of its action, being of such simple character that it requires absolutely no training or skill for its use. All that one is required to do is either to speak or to listen. It is able to transmit any language that is capable of being spoken, no matter what may be the character of its phonetic elements, provided a fairly clear articulate speech is employed. It will operate as well for an uncultured savage as it will for the most accomplished electric engineer. It should not be a matter of surprise, therefore, that the advent of this won-

Marvellous character of the speaking telephone.

Practical ubiquity.

derful device has to-day almost revolutionized methods of doing business. By its aid the modern business man becomes almost ubiquitous. He is able, with a velocity greater than that demanded by Puck, to speed along a particular wire, among the intricate network of wires that extend in all directions across a great city, or a section of country, and to enter the office or private room of his correspondent, obtaining almost instantaneous audience, and, transacting his business as well as if actually present, to then shut off communication and return to his office actually instantaneously.

Wonderful growth of the speaking telephone.

The rapid growth of the speaking telephone has been almost as marvellous as the instrument itself. In 1882, there were some 148 companies or private parties in the telephone business, employing some 54,319 receiving instruments, and using, in the transmission of messages, some 34,305 miles of conducting lines, with an actual outlay of capital invested in the business of some fifteen and one-half million dollars. In 1900, according to the report of the Bell Telephone Company, its various systems included about 1,500 exchanges, with 1,080,000 subscribers, employing 1,254,203 miles of conductors, and transmitting some 2,000,000,000 conversations per year. This business required an invested capital for the parent and the sub-companies of at least $300,000,000. Moreover, it must be remembered that the above figures are for the Bell Company only. During later years, numerous companies have come into existence that are entirely independent of the Bell Company. Those covering a part of the United States only had erected exchanges to the number of 2,750, with 700,000 subscribers, representing capital invested amounting to $150,000,000.

One telephone for every forty inhabitants in the United States.

So rapid has been the increase in the use of telephones in the United States that, at the beginning of this century, according to the Census Report for 1900, there was in the entire country one telephone in use for every 40 inhabitants, while, in some places, as, for example, in San Francisco, such use had reached the wonderful total of one for every 12.

When it is borne in mind that the telephone is now employed in every civilized country in the world, and is even in use to some extent in all parts of the world, the wonderful growth of this marvellous instrument will perhaps be better appreciated. Solomon's plaint concerning things that are new, referred to at the opening of a prior chapter, applies with special force to this great invention, so far as its early history is concerned.

Difference of opinion of the U. S. Courts and the scientific world as to inventor of the telephone.

Although the United States Court, after a most prolonged litigation, awarded the priority of the invention of the speaking telephone to Alexander Graham Bell, of the United States, yet a careful study of the facts would undoubtedly appear to award the credit for this invention to a German, Johann Philipp Reis, who produced an instrument, called by him the telephone, as early as 1860. Although it has been denied by some experts that the Reis apparatus is capable of transmitting clear articulate speech, yet equally able experts have sworn to the fact that not only would apparatus built in strict accordance with the Reis apparatus transmit articulate speech, but that models of such apparatus that were in existence long before Bell claimed to have invented the telephone, will still transmit speech. It will suffice, in this connection, to quote the following opinion of Prof. Sylvanus P. Thompson, from his interesting book, entitled "Philipp Reis, the In-

ventor of the Telephone." The Professor is referring to the statement, so frequently made, that the Reis telephone will only transmit musical notes. He remarks that, for such assertions, "the one reply is silence, and a mute appeal to the original writings of Reis and his contemporaries, and to the tangible witness of inexorable scientific facts. All the most important of these will be found in their appropriate place. They amply establish the following points:

Sylvanus P. Thompson on Reis's invention of the telephone.

"(1.) Reis's telephone was expressly intended to transmit speech.

"(2.) Reis's telephone, in the hands of Reis and his contemporaries, did transmit speech.

"(3.) Reis's telephone will transmit speech."

In addition to the above, it may be well to call attention to the fact that Edison, who invented the famous carbon transmitter, frankly admitted that he was started in his invention on the telephone by reason of a manuscript translation of a report on the Reis telephone; that he was aware that, in the Reis instruments, "single words, uttered as in reading, speaking and the like, were perceptible indistinctly, notwithstanding, here also the inflections of the voice, the modulations of interrogation, wonder, command, etc., attained distinct expression."

Edison acknowledges his inspiration by Reis.

Prof. Dolbear, the inventor of the static telephone, in a paper on the telephone read before the Society of Telephonic Engineers, March, 1882, in referring to the Reis instruments, stated:

Dolbear on the Reis invention.

"The speaker could testify that the instrument would talk and would talk well. The identical instruments would do that, so that Reis's transmitters would transmit, consequently, his receivers would receive; and Reis did transmit and receive articulate speech with such instruments."

In addition to the above, Moncel, in his book entitled "The Telephone," at least accords to Reis the merit of being the starting-point of the invention. He says, in this connection:

Moncel acknowledges the Reis telephone as the starting point of all telephone inventions.

"Nevertheless, it would not be just not to acknowledge that the Reis telephone formed the starting-point of all the others;" adding these pregnant words: "It is probable that, in this manner, as in the greater number of modern inventions, the original inventor obtained only insignificant results, and that it was the man who first succeeded in arranging his apparatus so as to obtain really striking results, that received the honor of the discovery and rendered it popular."

But it would be both impossible and unwise to enter any further into this controversy in a book of this character. It will be interesting, however, to give, in some little detail, a brief account of the early history of the telephone.

Reis's clear exposition of the principles of the telephone.

In a memoir published by Reis in the "Jahresbericht" of the Physical Society of Frankfort, for the year 1860-61, entitled "On the Telephone by the Galvanic Current," he clearly states both the principles according to which sound waves are propagated, and the manner in which such waves are able to carry different sounds to the human ear. He declares that it should be possible to transmit such sounds electrically. He points out the fact that every tone and every combination of tones that enters the human ear causes its membrane or ear drum to vibrate, and that such vibrations can all be represented by curves; that the motions of these vibrations produce the sensations of sound, and that every change in the motion must be accompanied by a change in the sensation. He claims,

therefore, that, as soon as it shall be possible, at any place and in any manner, to set up vibrations whose curves are like those of any given tone, or combination of tones, we shall receive the same impression as that tone or combination of tones would have produced upon us.

Reis then proceeded to describe the apparatus shown in our Fig. 35, as follows:

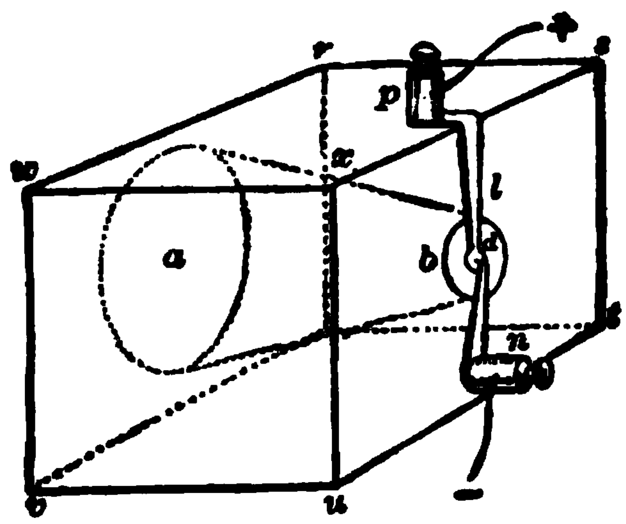


FIG. 35.—One of Reis's early forms of Telephone.

"Taking my stand on the preceding principles, I have succeeded in constructing an apparatus by means of which I am in a position to reproduce the tones of divers instruments, yes, and even to a certain degree the human voice. It is very simple, and can be clearly explained in the sequel, by aid of the figure: **Reis's description of his telephone.**

"In a cube of wood, *r s t u v w x,* there is a conical hole, *a,* closed at one side by the membrane *b* (made of the lesser intestine of the pig), upon the middle of which a little strip of platinum is cemented as a conductor of the current (or electrode). This is united with the binding-screw, *p.* From the binding-screw *n* there passes likewise a thin strip of metal over the middle of the membrane, and terminates here in a little platinum wire which stands at right angles to the length and breadth of the strip. **Transmitting instrument.**

"From the binding-screw, *p*, a conducting-wire leads through the battery to a distant station, ends there in a spiral of copper-wire, overspun with silk, which in turn passes into a return-wire that leads to the binding-screw, *n*.

"The spiral at the distant station is about six inches long, consists of six layers of thin wire, and receives into its middle as a core a knitting-needle, which projects about two inches at each side. By the projecting ends of the wire the spiral rests upon two bridges of a sounding-box. (This whole piece may naturally be replaced by any apparatus by means of which one produces the well-known 'galvanic tones.')

The receiving instrument.

"If now tones, or combinations of tones, are produced in the neighborhood of the cube, so that waves of sufficient strength enter the opening *a*, they will set the membrane *b* in vibration. At the first condensation the hammer-shaped little wire *d* will be pushed back. At the succeeding rarefaction it can not follow the return-vibration of the membrane, and the current going through the little strip (of platinum) remains interrupted so long as until the membrane, driven by a new condensation, presses the little strip (coming from *p*) against *d* once more. In this way each sound-wave effects an opening and a closing of the current.

. . . .

Action of the apparatus.

"But if these actions follow one another more rapidly than the oscillations due to the elasticity of the iron core, then the atoms can not travel their entire paths. The paths travelled over become shorter the more rapidly the interruptions occur, and in proportion to their frequency. The iron needle emits no longer its longitudinal tone, but a tone whose pitch corresponds to the number of interruptions (in a given time). But this is saying nothing

less than that the needle reproduces the tone which was imparted to the interrupting apparatus."

A form of the early Reis transmitter

The appearance of the transmitting and receiving instruments, as contained in a prospectus of instruction prepared by Reis to accompany instruments, is

B

FIG. 36.—Reis's Transmitting and Receiving Telephone contained in his Prospectus.

represented in Fig. 36. At A is the telephone or transmitting instrument; C the reproducing apparatus or receiver; B represents part of the conducting wire that connects the two stations. The electromagnet, placed on the side of the transmitting

FIG. 37.—Yeates's Electro-magnetic Receiver for Reis's Telephone.

instrument, is for the purpose of signalling. As regards this apparatus, Reis, in this prospectus, says: "Besides the human voice (according to my experience), there also can be produced the tones of good organ pipes."

Yeates's receiver.

One of the Reis telephone sets was sold to a Mr. Yeates, an instrument-maker of Dublin, who replaced the knitting-needle electro-magnet by an electro-magnet mounted on a sounding box, as shown in Fig. 37. Yeates exhibited this instrument at a meeting of the Dublin Philosophical Society, in November, 1865, when singing and words were transmitted.

Leaving now the question of the Reis invention, we come to that of Bell. Bell filed an application for a United States patent on February 14, 1876. The appearance of his original apparatus is shown in Fig. 38. This apparatus is described in the language of his specification as follows:

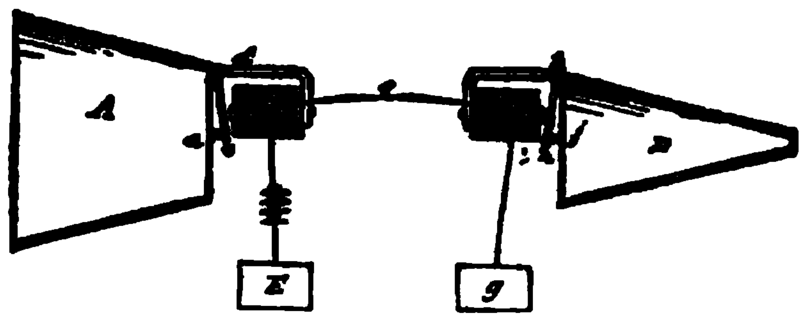


FIG. 38.—Bell's Original Telephone. This form was employed in his patent application of Feb. 14, 1876.

Bell's description of his telephone.

"The armature *c* is fastened loosely by one extremity to the uncovered leg *d* of the electro-magnet *b*, and its other extremity is attached to the centre of a stretched membrane, *a*. A cone, A, is used to converge sound-vibrations upon the membrane. When a sound is uttered in the cone the membrane, *a*, is set in vibration, the armature, *c*, is forced to partake of the motion, and thus electrical undulations are created upon the circuit E, *b*, *e*, *f*, *g*. These undulations are similar in form to the air vibrations caused by the sound; that is, they are represented graphically by similar curves. The undulatory current passing through the electro-magnet, *f*, influences its armature, *h*, to copy the motion of the armature *c*.

A similar sound to that uttered into A is then heard to proceed from L."

This form of apparatus does not appear to have been able to transmit intelligible speech. Bell, himself, said respecting it, "The results were unsatisfactory and discouraging." Consequently, he had a modified form of the instrument constructed, which he exhibited, during the summer of 1876, at the Centennial Exhibition of Philadelphia.

The general construction and appearance of this apparatus is shown in Fig. 39. The transmitter

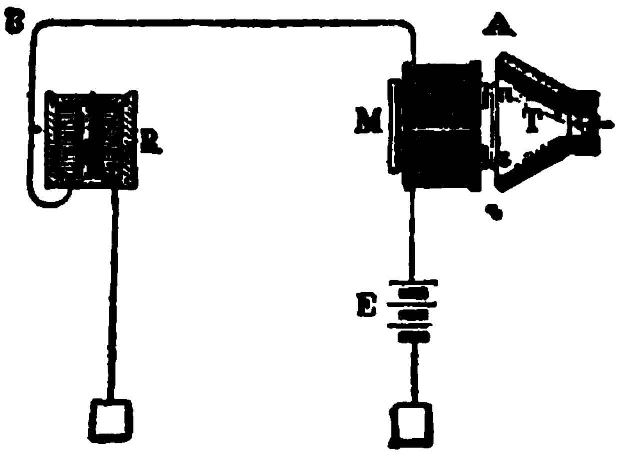


FIG. 39.—Bell's Modified Telephone, as exhibited at the Centennial Exhibition at Philadelphia during the summer of 1876.

is represented at A. On speaking into the tube T, a to-and-fro movement or vibration is imparted to the membrane stretched tightly over the other end of the tube, and the small, light, permanent magnet *ns*, cemented to the membrane, as shown, is moved to-and-fro before the poles of the electro-magnet M, placed in the circuit of the battery E. The magnetic flux of the permanent magnet *ns* is caused in this way to empty and fill the coils of wire wound on the electro-magnet M, so that, by magneto-electric induction, electrical currents are generated in these coils. Consequently, the currents so set up are alternating currents, and change the direction of

Bell's telephone as produced at the Centennial Exhibition in 1876.

their flow in exact accordance with the to-and-fro movements of the membrane. Moreover, the intensity of such currents corresponds to the extent of the to-and-fro movements of the diaphragm. The alternating currents so produced traverse the conducting circuit, and reaching the receiving end of the line, produce in the electro-magnet of the receiver R variations both in the strength and direction of the polarity of its electro-magnetism, thus setting up a motion in an iron plate or diaphragm placed near the pole of the electro-magnet. In this way there are reproduced words that were sung or spoken in the mouthpiece at T.

Operation of the apparatus.

In the specification of Bell's first patent, the following statement is made:

"Electrical undulations, induced by the vibration of a body capable of inductive action, can be represented graphically, without error, by the same sinusoidal curve which expresses the vibration of the inducing body itself, and the effect of its vibration upon the air; for, as above stated, the rate of oscillation in the electrical current corresponds to the rate of vibration of the inducing body; that is, to the pitch of the sound produced. The intensity of the current varies with the amplitude of the vibration; that is, with the loudness of the sound; and the polarity of the current corresponds to the direction of the vibrating body; that is, to the condensations and rarefactions of air produced by the vibration."

Bell's explanation of the action of his apparatus.

This explanation is practically the same as that given by Reis in 1860. Moreover, the curves employed by Bell to illustrate these principles are almost identical with those employed at an earlier date by Reis, for a similar purpose.

Practical identity of curves of Reis and Bell.

It is an interesting fact that, on the 14th of Feb-

ruary, 1876, exactly the same day on which Bell filed his application, Elisha Gray, of Chicago, filed a caveat in the United States Patent Office, for "A new art of transmitting vocal sounds telegraphi cally." Like Bell, Gray modified his form of apparatus, and greatly improved it for the transmission of speech. This modified form is shown in Fig. 40. Here the transmitting instrument consists of a mouthpiece, T_1, into which a person speaks, and a receiver, T, at which one listens. The transmitter is provided with a diaphragm, D_1, that is, a circular plate, formed of some elastic metal, which is securely fixed at its edges to the larger opening of the mouthpiece, so that it is capable of vibrating in ac-

Gray files caveat for telephone on the same day that Bell files his application for a patent.

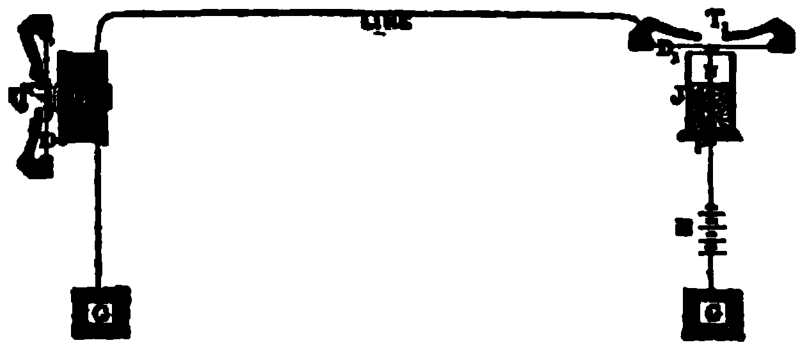


FIG. 40.—Gray's Modified form of Telephone. Note the manner in which the current strength is varied by the to-and-fro movements of the diaphragm.

cordance with the complicated vibrations produced by the human voice in speaking. A voltaic battery, E, grounded at G, is connected with the line through a conducting liquid, J, and through a metallic point N, connected with a metallic diaphragm, D_1. This liquid substance is of the same specific resistance as the metal point which dips into it, and is incapable of acting chemically on such point.

Manner of operation of Gray's telephone.

When, now, a speaker talks into transmitter T_1, against the diaphragm D_1, the diaphragm vibrates to-and-fro, and the resistance of the circuit will vary, decreasing as the diaphragm moves toward

the liquid, and increasing as it moves away from it. Consequently, these to-and-fro movements of the diaphragm D_1 vary the current strength which passes over the line, and these variations reproduce, in the diaphragm of the receiving instrument T, all the movements of the diaphragm of the transmitting instrument, so that one listening at T will hear all that is spoken or sung at T_1.

Dolbear.

During the autumn of 1876, Prof. A. E. Dolbear, of Boston, made a great improvement in telephonic apparatus, by means of which it became possible to employ the same instrument for either transmitting or receiving speech. Dolbear did away entirely with

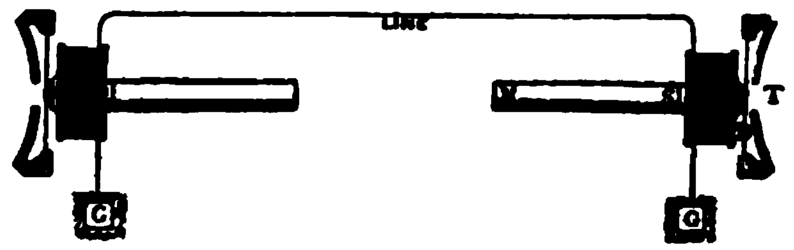


FIG. 41.—Dolbear's Magneto-Electric Telephone. Note the manner in which the transmitting instrument acts as a voice-driven dynamo, and the alternating currents generated drive the receiving instrument as a motor.

Dolbear's magneto-electric telephone.

the voltaic battery, and employed permanent magnets of steel at both the transmitting and the receiving end of the station. The appearance of this form of apparatus is shown in Fig. 41, where the permanent steel magnet N S is provided, near one of its poles, with a coil of insulated wire, and this pole is placed near a diaphragm, D, made of thin, soft sheet iron. A similar apparatus is placed at the other end of the line. In this, and in some of the preceding, apparatus, the ends of the line are represented as being grounded; that is, connected with metallic plates that are sunk in the earth. In such case, the earth forms a part of the conducting circuit. On account of the extreme delicacy of the telephone, metallic circuits are now generally em-

ployed in practice; that is, circuits in which a conducting line of metal, either of copper or iron, is employed for both the transmission and the return conductors.

The magneto-electric telephone affords an excellent example of the ease with which mechanical energy can be changed or converted into electric energy, and electric energy changed or converted into mechanical energy. The plates of soft iron, placed near the permanent magnet poles, are rendered magnetic by induction. These plates, taken in connection with the coils of wire surrounding the permanent magnets, constitute, in point of fact, a dynamo-electric machine that is driven by the energy of the voice of the speaker. The mechanical energy of the sound waves that strike against the diaphragm causes it to move toward and from the pole of the permanent magnet. During these movements, the coils of insulated wire on the permanent magnet are filled with and emptied of magnetic flux, so that E.M.F.'s are produced by induction in such coils just as they are in the coils of wire on the armature of the dynamo during its movements before the poles of the field magnets. But, as we have already seen, any dynamo or generator is capable of acting as a motor when its circuit is traversed by electric currents. Consequently, the similar combination of parts at the other end of the line is capable of acting as an electric motor, so that, when the alternating electric currents transmitted over the line wire are passed through the coils of this electric motor, the diaphragm of soft iron will be caused to move toward and from the magnet poles, so as to exactly reproduce the movements of the transmitting diaphragm that produced such currents.

The transmitting magneto-electric telephone a voice-driven dynamo.

The receiving magneto-electric telephone an electric motor.

In order to render this clear, let us take the case of the magnetic telephone and circuit, shown in Fig. 42, where, at each end of the line, a steel bar is provided with a magnetizing coil, wrapped around it near one of its ends, and placed, as shown, near a diaphragm of soft sheet iron. Now let us suppose that a circuit is formed of these two instruments, as shown, and consider what will happen when a single movement of the diaphragm occurs at either end. Let us say the diaphragm *a* is moved toward the magnet pole. Under these circumstances, the coils of wire on the magnet will be filled with magnetic flux from *a*, and currents will be produced which flow, say in a direction in which they leave the coil, and, passing through the ground, enter the coil of

Explanation of action of magneto-electric telephone.

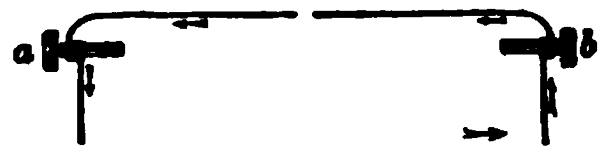
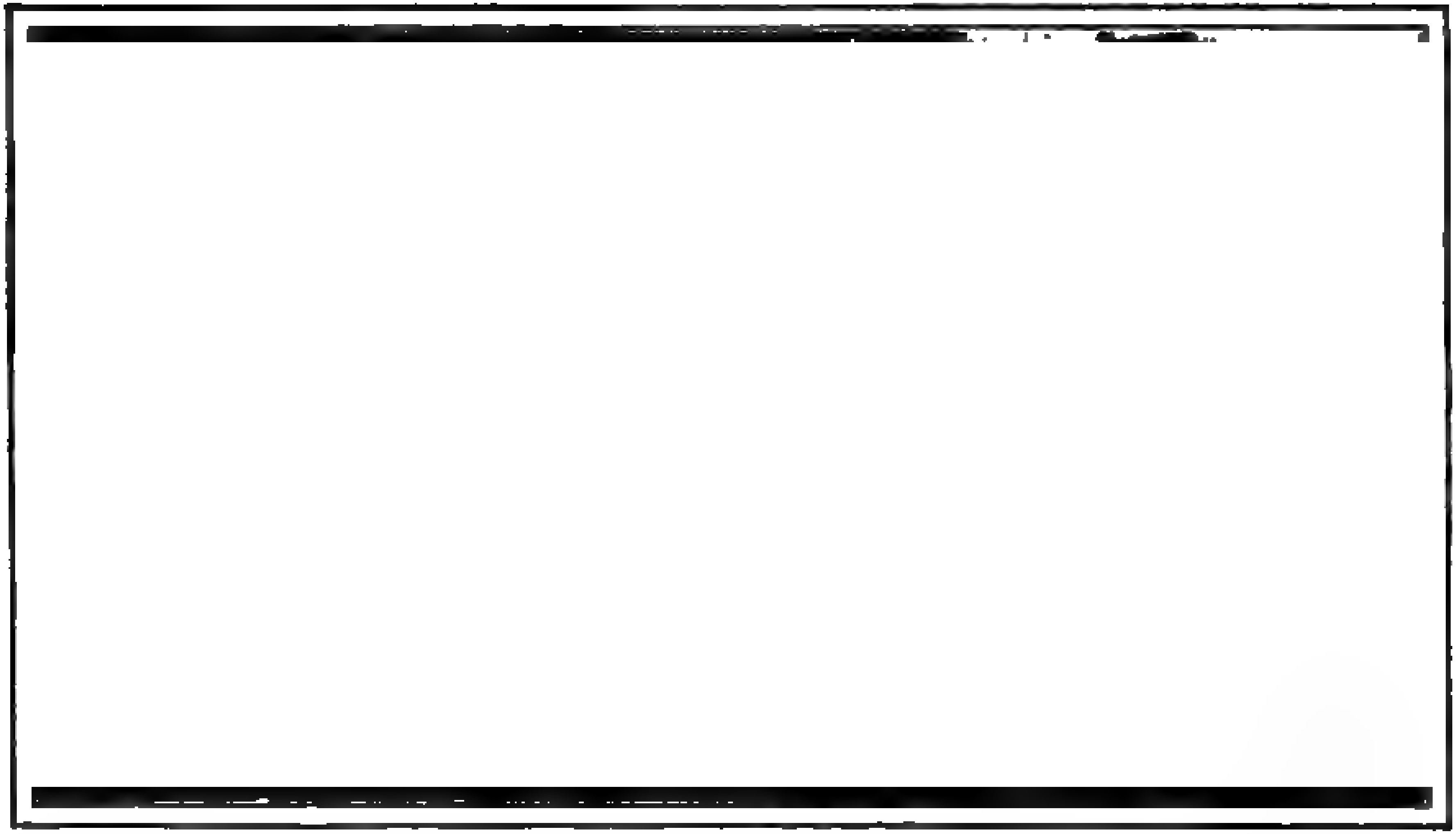


FIG. 42.—Magneto-Electric Telephone and Circuit. Note that here there is no voltaic battery, the magnetic flux being produced by the magnetism of the permanent magnets and the amount of flux passing through the coils being varied by the movements of the soft iron armatures or diaphragms.

wire at *b*. Let us suppose, moreover, that this current passing through the coil of wire *b*, increases its magnetism, and, therefore, draws or attracts the diaphragm at *b*, and so causes it to move toward the pole. If now, on the contrary, the diaphragm at *a* moves from its magnet pole, a current will be produced in the coils at *a*, in the opposite direction, or will now leave the coil and flow over the line, and, passing through the coil of wire at *b*, will weaken its magnetism, and so permit the elasticity of the diaphragm at *b* to move it away from the magnet pole. In this way, any movement of the diaphragm at *a* will be capable of producing currents that will cause exactly similar movements to take place in the



MAKING PHONOGRAPH RECORDS

A full instrumental band is here playing a stirring march for the sole benefit of a phonograph. The large brass horn, the all-attentive ear of the instrument, is seen in the centre. Phonographs are often operated by small electric motors

diaphragm at *b*. Consequently, any one listening at *b* will be able to hear whatever is spoken at *a*. In actual practice, it has been found more convenient to place both transmitting and receiving instruments at each end of the line, to employ a voltaic battery or other source to send currents through the coils of the electro-magnet placed on the receiving instruments, and to employ a metallic circuit instead of a ground-return. **Manner in which the receiving instrument operates.**

Both Bell and Gray appear to have been led to their inventions in the telephone by reason of their prior work in the field of multiple telegraphy. Both of these inventors had devised practical means for rendering it possible simultaneously to transmit several messages over a telegraph wire by employing currents corresponding to different sounds or tones on the line, and so arranging the receiving instruments that each instrument would be able to respond to only a single one of these tones.

At about this time Edison also was experimenting with a system of multiple telegraphy, and among his many experiments in this direction he employed a Reis transmitter, in which a drop of water was inserted between the platinum point and the diaphragm. He employed, in connection with this transmitter, a variety of electro-magnetic receiver, in which an electro-magnet was provided with a circular diaphragm of thin sheet iron. At first Edison proposed to employ various conducting liquids, into which a conducting metallic point, connected with the centre of the diaphragm, dipped, just as in the case of the Gray telephone. He afterward abandoned this method, and replaced the liquid by various conducting powders, such as metallic powders, powdered carbon, graphite, etc. In this, as we shall **How Edison began his telephone investigations.**

shortly see, he made a great improvement in the telephone.

Dust telephone transmitter.

Several inventors have followed Edison in the employment of granular carbon for telephone transmitters. Such transmitters are called dust transmitters. Their general construction will be better understood from an examination of Fig. 43. Here BBB is a wooden box, provided with a cover CC, in the shape of the mouthpiece shown. A diaphragm P, of platinum foil, is clamped at its edges in the usual manner. A circular carbon plate, N, is placed at such a distance from the platinum plate P as to leave a small circular recess that is filled with the

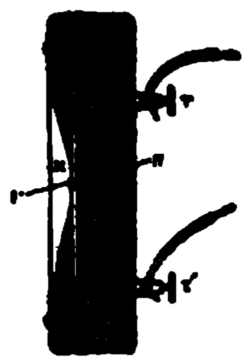


FIG. 43.—Dust Transmitter for Telephone. Note the position of the dust between N and P, to which the terminals T and T' are respectively connected.

granular carbon. The battery terminals T, T_1, are connected respectively to the carbon and the platinum plates. When the sound waves strike against the diaphragm and cause it to move to-and-fro, the resistance of the granular carbon will be varied, and will produce corresponding variations in the amount of current that passes through the line. Consequently, there will be reproduced, at the receiving diaphragm, movements corresponding to those of the transmitting diaphragm. Besides the granular carbon transmitter, Edison also constructed carbon transmitters made of solid buttons of carbon, placed between a movable and a fixed diaphragm.

Action of dust transmitter.

Dolbear, to whom reference has been made in connection with the electro-magnetic telephone, devised a form of receiver in which the movements of the receiving diaphragm were produced by electro-static attractions and repulsions. This ingenious piece of apparatus depends on the well-known fact that similar charges repel each other and dissimilar charges attract each other. As is well known, in the case of the induction coil, when a battery current is sent through the primary, there is produced in the secondary coil, at the moment of closing the primary circuit, a current that flows in the opposite direction to that in the primary, and that a current is similarly produced in the secondary, which flows in the same direction as that in the primary at the moment of breaking the primary circuit. When the terminals of the secondary are not connected, instead of the current passing, there will simply be E.M.F.'s produced, that will cause the potential of one of the terminals to be higher than that of the other. In other words, an induction coil can be employed to produce electric charges.

Dolbear's electro-static telephone receiver.

Dolbear employed the above-mentioned principle for the production of an electro-static telephone in the following manner: Two metallic disks, C and D, Fig. 44, covered with a film of varnish, and insulated from each other by hard rubber or other suitable material, have an air space left between them. One plate only is left free to move under the influence of the electric charges on the two plates. A suitable mouthpiece, C′, is provided, as shown in the figure. These disks act like a Leyden jar, the air space between them being the dielectric, and, like any other Leyden jar, may receive a permanent charge, and act like an exceedingly sensitive electroscope. In practice, the two plates are connected with

Construction and operation of Dolbear's electro-static telephone.

the two terminals of an induction coil. The circuit of the primary is connected with a telephone transmitter of any suitable type. When a speaker talks against such transmitter, he interrupts or varies the current through the primary, and thus causes an action to occur in the secondary, which results in variations of the charges on the plates of the receiver, so that whatever is spoken into the transmitter can be heard in the receiver.

FIG. 44.—Dolbear's Electro-static Telephone. Note the Leyden jar formed by the plates C and D with their intervening air space.

Hughes's microphone

A form of apparatus produced during the early days of the telephone by Professor Hughes, of England, for the purpose of rendering faint, indistinct sounds distinctly audible, depended for its operation on the changes that result in the resistance of loose contacts. This apparatus was called the microphone, and was, in reality, but one of the many forms that it is possible to give to the telephone transmitter. For example, the Edison granular transmitter was a variety of microphone, as was also Edison's transmitter, in which the solid button of carbon was employed. Indeed, even the platinum point, which, in the early form of the Reis transmitter, pressed against the platinum contact

cemented to the centre of the diaphragm, was a microphone. In all cases of loose contacts, the faintest sound or whisper causes the sound waves that impinge against the loose contacts to alter the resistance of any circuit in which they are placed, sufficiently to permit sounds to be heard in a telephone receiver connected with such circuit.

The loose contact of the microphone may take a variety of forms. The form first given to it is shown in Fig. 45, where a rod of carbon, E, pointed

FIG. 45.—Hughes's Microphone. Note the loose contacts between the double-pointed carbon pencil E and the supporting carbons B and C.

at both ends, is inserted in small holes near the ends of two crosspieces of carbon, B and C, supported on a wooden board, A, which acts as a sounding-board. Conducting wires, *a* and *b*, were connected respectively to the crosspieces C and B. Under these circumstances, talking or singing in the neighborhood of the sounding-board could be heard in a telephone receiver, placed in circuit with the microphone and the voltaic battery.

Hughes's microphone

Another form of microphone is shown in Fig.

46, where loose and imperfect contacts are obtained by a number of nails, c, c', c, placed in the position shown. Here two of the nails are connected with the terminals of the battery P, and with the circuit of the telephone T. If these nails are bridged over by a third nail, placed across them as shown at c', speaking or singing in the neighborhood of the nails will vary their resistance. Any one, therefore, listening at the telephone connected with the circuit, will be able to hear what is spoken or sung in the neighborhood of the nails.

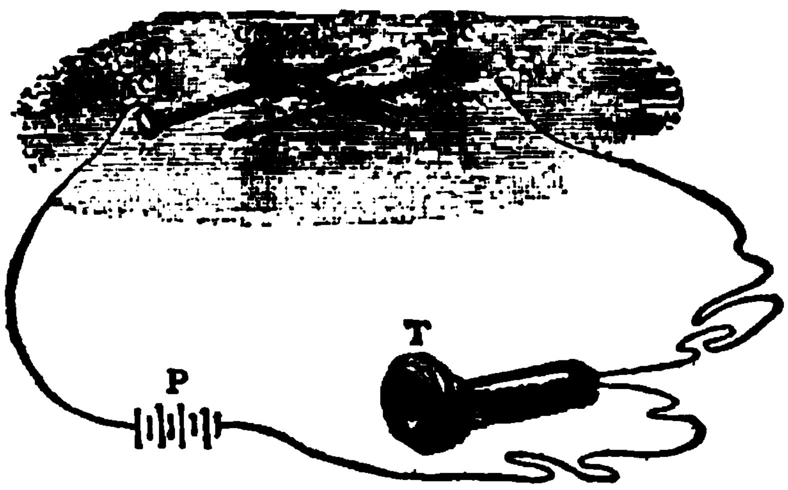


FIG. 46.—Simple Microphone Circuit.

To hear a fly walk.

It was properly regarded, at the time of the production of the microphone, as a very remarkable circumstance that the instrument was so delicate that the mere walking of a fly over the sounding-board of the instrument could be distinctly heard at a distance of many miles. Indeed, by employing a powerful battery, the loudness of the fly's footsteps was so increased that some observers have declared that the sounds approached in loudness those of the tramping of a horse.

Telephone work of Jas. W. McDonough.

In addition to the early work of Reis, Bell, Dolbear, and Edison, there should some reference be made to that of James W. McDonough, who filed an application in the United States Patent Office,

on the 10th of April, 1876, for what he called the "Teleloge," or means for transmitting articulate sounds from one place to another through the medium of electricity. McDonough was one of the many parties who were included in the famous interference suits with Bell in the United States Patent Office, for priority of invention of the speaking telephone. The suits were long and bitterly fought, and included, besides Edison, Dolbear, Gray, and McDonough, Berliner, Blake, and others. The final result of the interference was the award to Bell of a general patent.

There was still another claimant for the honors and profits of the invention of the telephone; viz., Daniel Drawbaugh, who claims to carry the date of his invention far back of the others, but we have already given to this part of the history of the art as much space as can be spared, and we shall, therefore, content ourselves to the mere reference as above.

Daniel Drawbaugh.

CHAPTER VII

SOME ACCESSORIES OF THE TELEPHONE

"The difference between Edison's carbon transmitter, and the microphone in its simple form as constructed by Hughes, is very slight; but the Edison form has disappeared, and in the same way as all magnetic telephones are more or less imitations or modifications of the original Bell instrument, so all carbon transmitters are now modifications of Hughes' ingenious apparatus. The number of these imitations is legion; but most of them are modifications without much practical value."—*The Telephone:* PREECE and MAIER

THE telephone, as it is in use to-day, in this and other parts of the world, almost invariably employs the microphone carbon transmitter in the form of a granular carbon or a dust transmitter. Carbon, first employed in telephony by Edison, possesses great advantages over any other substance for microphone transmitters, mainly for two reasons. In the first place, unlike most other substances capable of being employed for this purpose, carbon is practically unalterable in air at ordinary temperatures, since it is not rusted or oxidized by air, as are most of the ordinary metals. In the second place, unlike these metals, its electric resistance decreases as its temperature increases.

Why carbon is so valuable for microphonic contacts.

There is even yet some difference of opinion as to just how to account for the decrease in the resistance of a telephone transmitting circuit containing two carbon surfaces in microphonic contact. It is, however, conceded by most that the nature of this action is as follows: whenever, under the influence of sound waves, an increase of pressure is brought to

Action of carbon microphonic contacts.

bear against the carbon contacts, the first effect is to increase the extent of surfaces in contact, and thus decrease the resistance. The increase of current that will then pass through such circuit will cause an increase in temperature at the contact surfaces, and such increase in temperature will still further decrease the resistance of the circuit, and thus still further increase the strength of the current passing through it. It is for these reasons that carbon, in some form or other, is now employed in practically all the great commercial installations of the telephone.

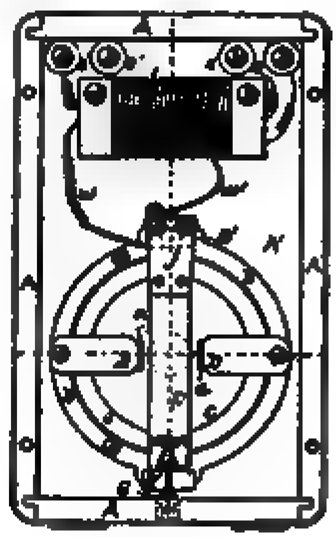


FIG. 47.—Blake Telephone Transmitter.

A form of carbon transmitter, that was very generally employed in the United States until quite recently, is known as the Blake transmitter, an invention of Francis Blake, of Boston. This transmitter is seen in Fig. 47, in front and in sectional views. A metallic ring, B, serves as a frame for holding the mechanism of the instrument. The diaphragm C, against which the sound waves produced by the speaker's voice strike, is formed of a

Construction of the Blake carbon.

fairly heavy piece of sheet iron, and is firmly supported in a frame against a rubber ring, *r*. Two damping springs, D, D, bear against the surface of the diaphragm in the positions shown. These springs rest on small pieces of rubber, *a, a*. It has been found advisable to employ damping springs in transmitting diaphragms, in order to prevent too great movements of the diaphragm, as well as to keep portions of the plate from vibrating, it being necessary in order to ensure the best operation of the instrument that the plate vibrate as a whole. An adjusting lever, F, attached to a spring, *j*, is provided at its lower end with an adjusting screw, G. A small bar of platinum, *e*, has one of its ends resting against the centre of the diaphragm, while its other end terminates in a blunt point that is in contact with the back electrode *e'*, consisting of a block of carbon. The front electrode *e* is independently supported on a light spring, *c*, mounted on the lever F, but insulated from it. The back electrode *e'* is set in a brass block, G, of considerable weight, mounted on the spring *d*. The springs *d* and *c* tend to oppose each other. In this transmitter, therefore, both electrodes are supported in such a manner as to move freely with the diaphragm. The outer electrode, however, on account of its weight, offers, by reason of its inertia, sufficient resistance to the small and rapid movements of the diaphragm to produce variations in the pressure between the electrodes, and so produce changes in the resistance of the circuit. I is an induction coil, whose circuits are connected with the two electrodes. The Blake transmitter is a very sensitive instrument. It was subject, however, to some difficulties in actual practice, and has lately been almost entirely replaced, especially for long-distance transmission, by a form of transmitter called the solid back transmitter.

Manner of operation of Blake transmitter.

Solid-back telephone transmitter.

The solid back transmitter is another form of the granular carbon transmitter. Its general appearance is shown in Fig. 48, a section of the instrument being seen in the upper part of the figure, and the separate parts of the resistance button being shown at the bottom. The diaphragm D, receiving the sound waves, is made of a sheet of aluminium, is held securely in place between two rubber rings, and is provided with two damping springs *f*, *f*, as in the Blake transmitter. Two blocks of carbon, B and E, serve respectively as the front and back electrodes.

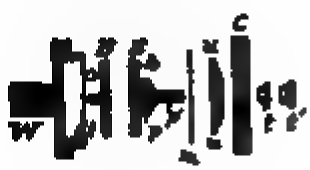


FIG. 48.—Details of Solid-back Telephone Transmitter.

General construction and operation of solid-back transmitter.

B is immovable, being supported in a heavy metallic block, W, while E is carried on the face of a metallic piece, *b*, furnished with a screw-threaded portion, *p′*, which serves to connect it rigidly with the centre of the diaphragm D, and is, therefore, movable. A mica washer, *m*, sufficiently large to completely cover the cavity in the block W, when the electrodes are in place, is supported on the enlarged screw-threaded portion *p* of the metallic piece *b*. The carbon electrodes are of slightly smaller diameter than the interior of W, which is lined with paper.

There is, therefore, a fairly considerable space around the electrodes, and this, as well as the space between the carbon electrodes, is filled with granular carbon. Any vibration of the diaphragm D, under the influence of the sound waves, is transmitted directly to the front electrode E, which is able to vibrate by reason of the elasticity of the mica washer *m*, the back electrode being stationary. A better general idea of the solid-back transmitter may be obtained from the sectional view of the instrument shown in Fig. 49.

FIG. 49.—Sectional View of Solid-back Telephone Transmitter.

Carbon transmitter cause of change.

It was the introduction of the carbon transmitter that practically caused the change to be made in the practice that was generally followed before such introduction, in the employment of the same character of transmitting and receiving instruments. The magneto-electric telephones introduced into the art by Dolbear, and afterward employed by Bell, as shown in Fig. 42, were of this type, so that the same instrument could be used alternately as a transmitter and as a receiver. Before the use of the

carbon transmitter, many attempts were made to increase the strength of the tones reproduced in the telephone receiver, and, although some of these succeeded in obtaining a fairly great increase, yet such increase was, as a rule, more than offset by a decrease in the clearness of the transmitted speech.

The use of the microphone transmitter, of course, necessitated the use of a transmitting and a receiving instrument at each end of the line. By the use of improved forms of carbon transmitters, the strength and clearness of the transmitted speech were considerably improved. But there was another instrument added about this time which greatly increased the distance over which it was possible to transmit speech. This was the induction coil, a piece of apparatus that is now invariably employed in connection with telephonic transmission. It will be necessary, therefore, to inquire into the action of this important accessory to the telephone.

Use of the induction coil in telephonic communication.

Where a telephonic circuit employs a microphone transmitter, the operation of the receiving instrument is dependent entirely on the variations in the current strength sent over the line, by reason of variations in the resistance of the microphone contacts, and is independent of the strength of the current that is constantly passing. Even in the most delicate forms of microphonic transmitters, as, for example, in the solid-back transmitter just described, the total variation that it is possible to obtain in the resistance of the contacts under the influence of the sound waves is at the best but small. For successful operation, it is necessary that this small resistance shall constitute an appreciable part of the total resistance of the circuit, and this is done by the use of the induction coil in the following manner:

Why the induction coil is advantageous in telephony.

The total resistance of a telephone circuit employed for fairly long-distance transmission may amount to say 1,000 ohms. The greatest variation in the resistance of the circuit of a modern microphonic contact would not amount to more than say 1 ohm. If, therefore, a microphonic transmitter be placed directly in a circuit whose resistance is 1,000 ohms, and is able, at the best, to change the resistance of such circuit to the extent of but 1 ohm, this would only amount to a change in the total resistance of the circuit of $\frac{1}{1,000}$ of its value, and the decrease in the strength of the current flowing through the line would only be $\frac{1}{1,000}$ of its value. If, however, this transmitter be placed in a local circuit consisting of the primary of an induction coil and a local battery, whose resistance need not be greater than say 5 ohms, then a change in the resistance of the contacts of 1 ohm would amount to a change as great as $\frac{1}{5}$ of the total resistance, so that a change of $\frac{1}{5}$ or 20 per cent of the current passing in the circuit might be obtained. An induction coil will, therefore, permit the sound waves to produce a much greater variation in the current strength passing in the line than would be possible were the microphonic contacts placed directly in the line circuit.

Advantage resulting from placing the microphone transmitter in a local circuit of small resistance.

The local circuit of low resistance obtained by the use of an induction coil is shown in Fig. 50. Here P, the primary of the induction coil, together with B, a small battery, are placed in the low-resistance closed circuit shown; while S, the secondary of the coil, and R, the telephone, are placed in the circuit of LL′, the transmission line.

Local low-resistance circuit.

But there is another advantage obtained by the use of the induction coil. By making the number of turns in the secondary circuit of the induction coil much

greater than in the primary circuit, there will be obtained an increase in the voltage of the current transmitted over the line. This permits a higher E.M.F. to be employed on the transmission line, so that the transmission can be made over much greater distances, with the use of much higher resistances in the line, than would otherwise be possible. Edison first employed the induction coil in telephony, and made this great improvement in the art.

Another advantage arising from use of induction coil.

Reference has already been made to the fact that the use of the magneto-electric telephone consists practically of a dynamo or generator driven by the voice of the speaker, coupled with a motor operated

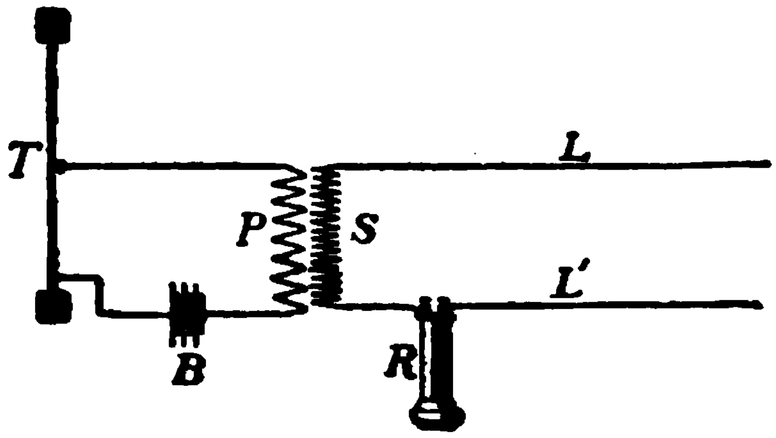


FIG. 50.—Low-resistance Circuit containing Microphone Contact and Primary of Induction Coil.

by the currents so produced. In the art of telephony, as improved by the use of an induction coil, we have, in addition to an indirect combination of a generator and a motor, the additional feature of a long-distance transmission system, in which a step-up transformer is ingeniously employed to raise the pressure transmitted over the transmission line.

The long-distance telephone transmission line

Since the carbon transmitter merely varies the strength of the current passing, producing what has been called an undulatory current, whose direction is always the same, its strength varying with the alternate to-and-fro motions of the diaphragm, it follows that undulatory currents, and not alternat-

ing currents, pass through the primary of the induction coil. The currents produced in the secondary, however, are alternating currents. Care is therefore necessary in the construction of the induction coil for telephonic purposes, to properly proportion the lengths of the primary and secondary coils in order to obtain the best results.

Induction coil of Western Telephone Construction Company.

A form of induction coil employed by the Western Telephone Construction Company is shown in Fig. 51. The core is formed of a bundle of 500 wires of soft iron, placed inside a fibre tube, provided with ends at E. In

FIG. 51.—Induction Coil for Telephone Work. Western Telephone Construction Company's type.

other words, the core of the induction coil is laminated. This is necessary in order to prevent the setting up of eddy currents, which would interfere with the proper operation of the coil. A primary, consisting of about 200 turns of silk-covered wire of fairly large diameter (No. 20, B. & S. wire gauge), is wound on the outside of the fibre tube. Several layers of oiled paper are then wrapped over the primary, when some 1,400 double turns of a thinner wire are wrapped side by side over the primary. These wires, when connected in parallel, have a resistance about equal to what would be pro-

duced by a single length of No. 31, of the B. & S. gauge. The resistance of the primary coils is .38 ohms, and that of the secondary coil is about 75 ohms.

The induction coil is sometimes placed in the same box as the transmitter, as is the case with the Blake transmitter, shown in connection with Fig. 47. The resistance coil is also sometimes placed in the desk set of transmitter and receiver.

The voltaic batteries employed in connection with induction coils are of various types. Some form of the Leclanche type is generally employed. Such batteries possess the advantages of being cheap, of being readily kept in order, only requiring the addition of a little water to replace that lost by evaporation, and, moreover, of having a comparatively low resistance, a matter of extreme importance in telephonic practice. Storage batteries are also employed extensively for telephone work, their high E.M.F. (2.2 volts) and low electric resistance eminently fitting them for this work. They are employed where a large current strength is required for operating a great number of transmitters, as, for example, in large central stations.

Voltaic and storage batteries.

In any system of telephonic communication, some means must be employed for the purpose of calling the party at the other end of the line to the 'phone. In the early days of the art, a common vibrating bell, operated by direct current from a small voltaic battery, was employed. As the distance of transmission increased, however, it was found that such batteries were unsuited to operate distant call bells. This has led to the almost universal employment of a hand-operated magneto-generator; although some-

times steam-driven generators are used. Such a generator, connected to the circuit of a call-bell, is shown in Fig. 52. The generator employs a shuttle-wound armature, of the Siemens type, rotated in a bipolar field, formed by connecting the cast-iron pole pieces P, P, to the poles of permanent magnet N S. No commutator is employed, alternating currents being applied directly for the operation of the call-bell.

Magneto-generator.

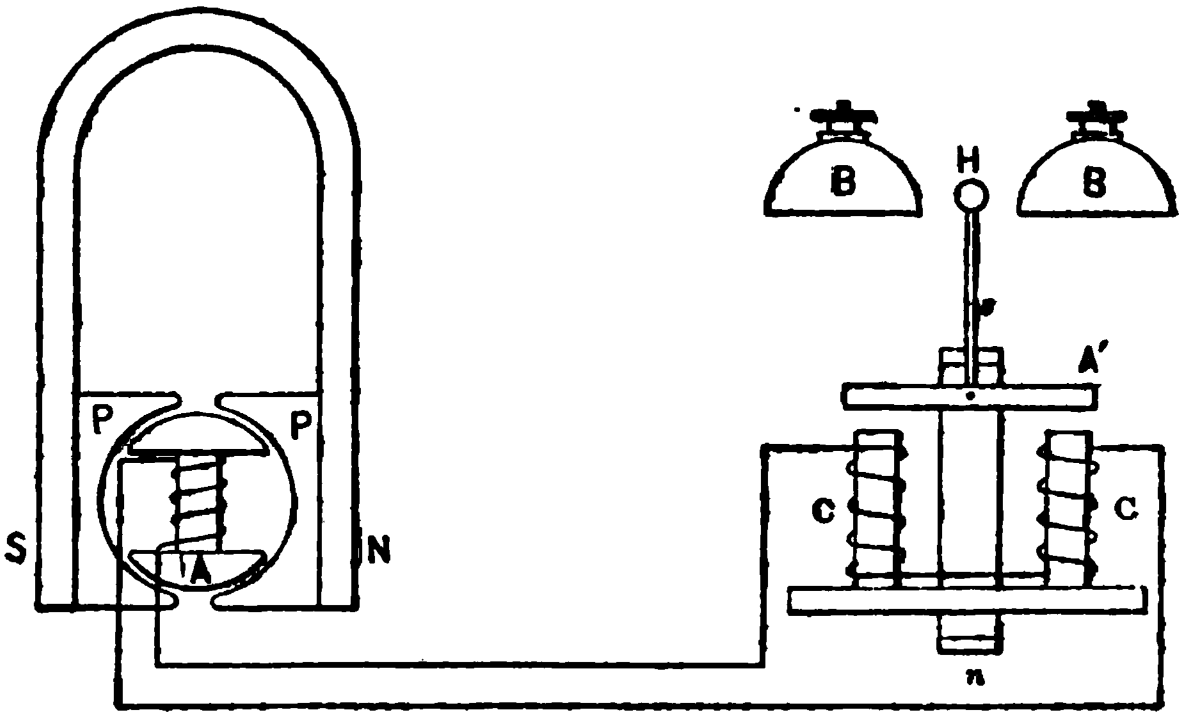


FIG. 52.—Circuit of Magneto-generator and Ringer. Note the position of the shuttle-wound armature between the pole pieces P, P, of the permanent horseshoe magnet N S.

The call apparatus is shown at the right-hand side of the figure, and is of the type generally known as a polarized bell or ringer. It is provided with magnetizing coils, C, C, connected directly with the circuit of the armature A. The soft iron armature A′, of the call-bell, is provided with a striking lever or hammer, H. This armature is pivoted in front of the magnet poles of C, C, and both the armature and the cores of the electro-magnet are permanently magnetized or polarized by means of the permanent magnet *ns*. This magnet produces south magnetism in the armature A′, and north magnetism in the pole pieces, the two coils C, C, being oppositely wound,

Polarized bell or ringer.

so that the passage of alternating currents through them tends to strengthen the magnetism of one pole, and to weaken the magnetism of the other pole. The passage of alternating currents, therefore, through the coils C, C, causes the polarity to rapidly vary, and the hammer H to be rapidly moved between the poles, thus sounding the bells B, B.

The high resistance of the many turns of wire wound on the armature of the magneto-generator, which, in some cases, is as high as 650 ohms, makes it desirable in practice to employ some device for

Automatic shunt for magneto-generator.

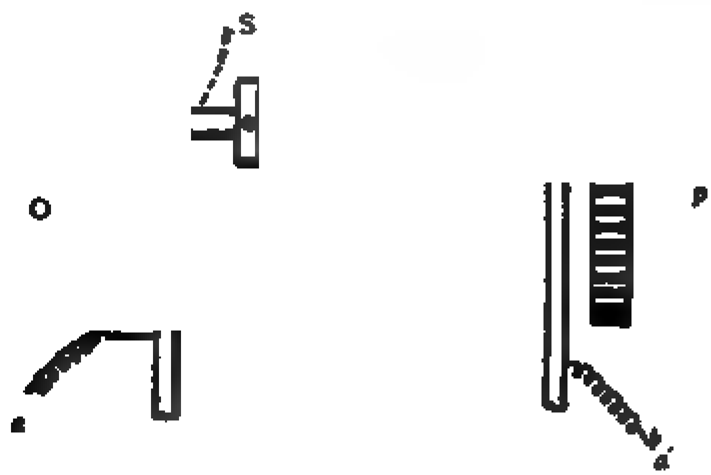


FIG. 53.—Automatic Armature Shunt for Magneto-generator.

cutting the armature out of the circuit when the generator is not in use. There are many devices that have been employed for this purpose. At first it was done by some hand operation, but it is now generally effected by means of an automatic device generally called an automatic shunt. A form of shunt in very general use is shown in Fig. 53. Here a gear wheel, G, mounted on the crank shaft S, is so arranged that it can move freely through a small fractional part of one rotation. When the generator is at rest, the line current entering at a' passes through a circuit of practically no resistance, con-

sisting of the crank shaft and the spring O, to the other line terminal *a*. When, however, the crank is turned, a pin, *p*, rises out of a notch in the hub of the gear wheel, and so draws the shaft out of contact with the spring O, thus breaking the shunt path of low resistance around the armature, and placing the latter in the circuit.

FIG. 54.—Magneto-generator for Telephone Call.

A magneto-generator is shown in Fig. 54. Here the bipolar field is obtained by the use of three permanent horseshoe magnets. The magnets of the call-bell are placed near the top of the box, the striking lever passing through an opening in the

FIG. 55.—Magneto Ringer. Note the position of the permanent magnet employed for polarizing the soft iron coils of the electromagnet.

box as shown. The appearance of a magneto-bell ringer is shown in Fig. 55, the permanent magnet employed for polarizing both the cores of the electro-

magnets and its armature being shown in front of the two magnet cores.

Where the telephone is placed in such position in a house that the people may, at times, be too far from the call-bell to be able to hear it, an additional

FIG. 56.—Extension Call-Bell. Note that this call-bell is of the same type as the magneto ringer shown in Fig. 55.

call-bell, called an extension bell, is employed. Such a bell is simply an additional bell placed in the call circuit, and is of the same general type and construction as the call-bell already described. An extension bell is represented in Fig. 56. An examination of this figure will show that it is similar in its construction to those of the preceding figures. **Extension call-bell.**

FIG. 57.—Single-pole Telephone Receiver.

Various forms are given to telephone receivers. Perhaps the greater number of receiving instruments employed in the United States consist of a compound permanent bar magnet, placed inside a

shell or casing of hard rubber. The external appearance of the receiver is shown in Fig. 57, and the general construction of the bar magnet in Fig. 58. The bar magnet is provided at one of its ends with a pole piece of soft iron, on which a coil of insulated wire is wound. This coil generally consists of two parallel wires (No. 38, B. & S. gauge), having a total resistance of 75 ohms. The end of the soft iron pole piece is placed near a diaphragm, consisting of sheet iron about $\frac{1}{100}$ of an inch thick.

Compound permanent bar magnet.

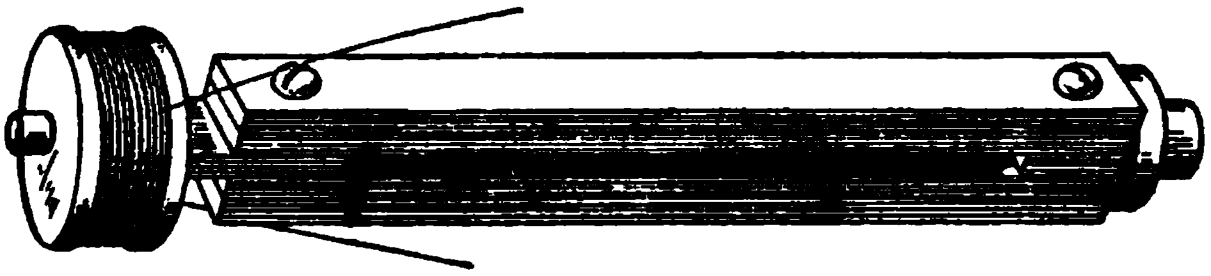


FIG. 58.—Compound-bar Magnet for Single-pole Telephone Receiver.

Sometimes a difficulty arises in practice in maintaining constant the distance between the free end of the soft iron pole piece and the sheet-iron diaphragm. This arises from the unequal expansion between the metal and the hard rubber. Various expedients have been adopted, which have remedied this difficulty.

CHAPTER VIII

TELEPHONE CIRCUITS

"Speech was made to open man to man."
—*State Worthies:* LLOYD

SINCE, in all forms of telephonic communication, where microphonic transmitters are employed, both transmitting and receiving instruments are necessarily placed at each end of the line, some means must be adopted for switching one or the other of these instruments out of the circuit when not required for use. It is necessary so to arrange matters that, when the instruments at either end of a line are not in use, they must be in a condition in which they can receive a call. In other words, the call-bell must be in the circuit as long as the instruments are not in use. Moreover, since the high resistance of the magneto generator would injure the sensitiveness of the apparatus, so as to render long-distance transmission impossible, some method must be adopted that will automatically remove such resistance from the circuit. This is generally done by means of an apparatus called an automatic telephone switch.

Necessity for some system of call-bells.

Many forms of automatic telephone switches have been devised. The automatic telephone hook switch, represented in Fig. 59, is in very general use. As represented in the upper part of the figure, the telephone has been placed on the end of the hook switch H, thus bringing the switch into contact with the conducting piece 3, and breaking the contact

Automatic telephone hook switch

with the conducting pieces 1 and 2; while, at the lower part of the figure, the telephone has been removed from the hook, and a spring, not represented in the figure, has pulled the hook upward, and brought it into contact with the pieces 1 and 2, breaking contact with the piece 3. Let us inquire what has been effected by these different movements.

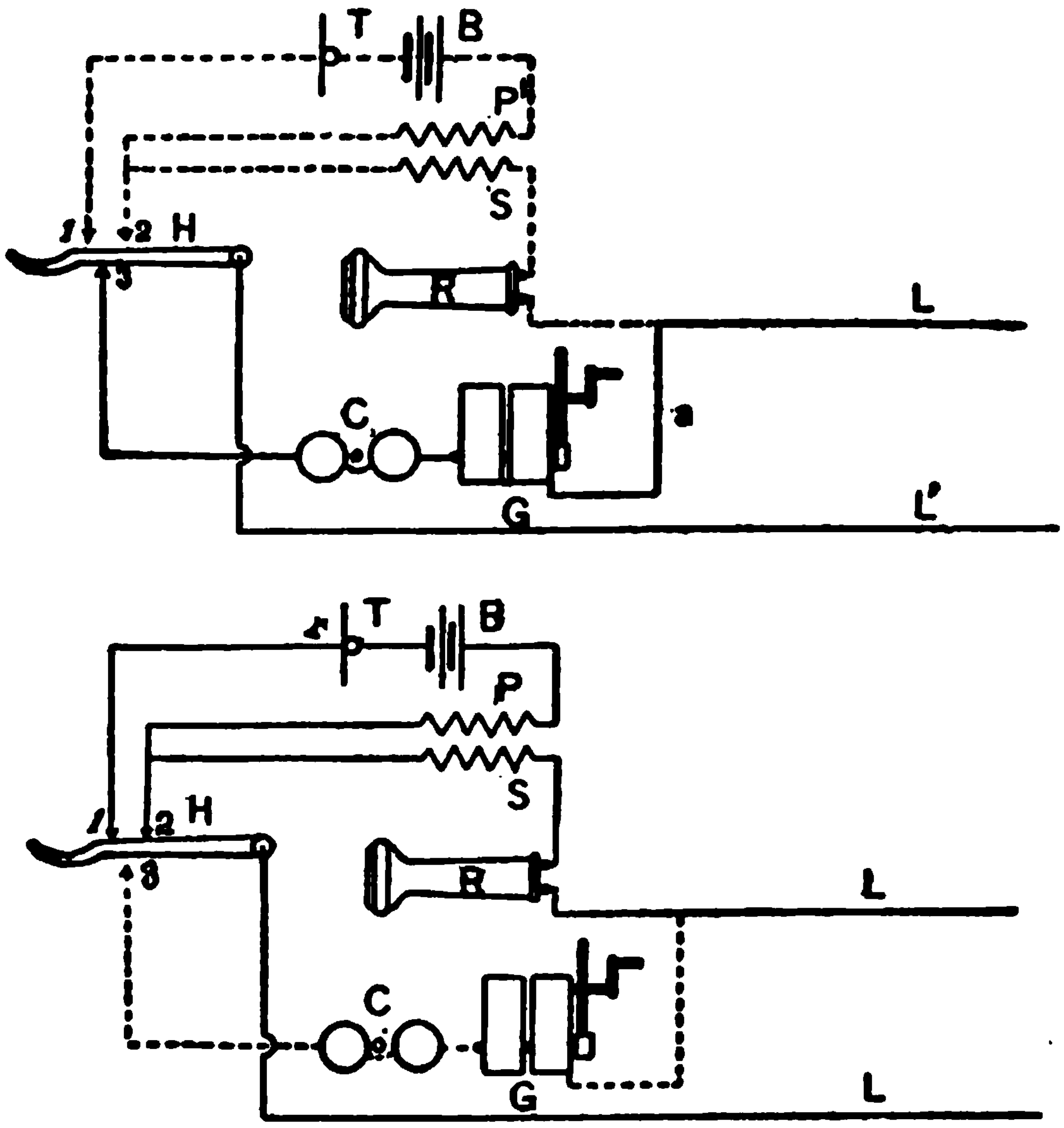


Fig. 59.—Automatic Telephone Switch. Hook down and hook up.

Condition of affairs when the telephone is on its hook.

We will suppose that the condition of affairs at the station is that indicated at the top of the figure, where no one is using the line, and where, consequently, the telephone is hanging on its hook. The hook switch H has been brought into connection, by the weight of the telephone, with the contact piece 3. In this position everything is cut out of the line except the magneto-generator G, and the call-bell C, the conductors at 1 and 2 having lost their contacts

REPORTING A BOAT RACE "FROM THE FIELD"

Telephoning and telegraphing bulletins of a college boat race at Poughkeepsie to a New York daily. Instruments were set up on a hillside, and connections made with New York by "tapping" a convenient wire

with the telephone switch. Indeed, if the automatic shunt, referred to in the preceding chapter, has been employed, as it is in practically all cases in telephone practice to-day, the coils of the generator also have been automatically cut out of the circuit. Of course, the coil of the call-bell C must be left in the circuit, so as to leave this station ready at any moment for an incoming call. In order to render it easier to understand this figure, the open circuits are represented by dotted lines, and the closed circuit by a full line.

Let us suppose that, under these circumstances, a call comes in from another station over the line wire L. It will pass by the armature of the generator, through the automatic shunt circuit, and the correspondent at this end of the line will now take his telephone from the hook and listen. The spring now draws the lever upward, breaks the contact with 3, and makes contact with 1 and 2, thus bringing about the state of affairs that is represented in the lower part of the figure, the dotted lines showing that the call-bell and generator have been cut out of the circuit, while the circuit of the battery B, the transmitter T, and the primary wire P, are closed for working by the closing of the contacts at 1 and 2.

Condition of affairs when telephone is removed from hook.

Various forms are given to telephonic apparatus. A very common form of transmitting and receiving instrument, combined in a form called the desk set, is shown in Fig. 60. Here the transmitter is mounted on a swivel arm at the top of the standard, so as to permit its height to be varied within certain small limits. In this case, the transmitter is a microphonic transmitter of the solid-back type. The automatic telephone hook, by means of which the different circuits are cut into and out of the circuit

Desk set of telephonic apparatus.

as above described, is placed at the side of the standard with the telephone hanging in position on the hook. Where sets of this character are employed, the call-bell is generally situated in the room at a convenient place on the wall, or at the side of the desk. In sets of this type, which are generally connected with central stations, a generator for producing the current for calling is located at the central station.

FIG. 60.—Desk Telephone Set, Consisting of Transmitting and Receiving Instruments.

Trouble arising from grounded telephone circuits.

We have, though only for the sake of convenience, shown in many of the figures of telephonic apparatus circuits where a ground-return is employed, calling attention, however, at the same time, to the fact that in practice the employment of such circuits was undesirable. We will now point out, somewhat in detail, the difficulties that arise from the use of ground-return circuits. Such difficulties consist generally in various noises and sounds that are heard in the receiving telephone. The telephone is such an extremely sensitive instrument that, in many cases, causes which appear to be insignificant may produce great disturbances. Miller, in his admirable work entitled "American Telephone Practice," from which some of the preceding cuts have been produced, thus very clearly describes the causes of these noises

in the case of a telephone circuit with a ground-return:

"Lines so constructed were, however, soon found to be subject to serious difficulties, chief among which were the strange and unaccountable noises heard in the receiving instruments. There are many causes for such noises, some of which are not entirely understood. The swinging of the wire, in such a manner as to cut through the lines of force of the earth's magnetic field, or the sudden shifting of the field itself, causes currents to flow in the line wire which may produce sounds in the receiver. On long grounded lines the variations in the potential of the earth at the ground plates, due to any cause whatever, will cause currents to flow in the line. The passing of clouds or bodies of air charged with electricity will induce charges in the line, and cause currents to flow to or from the earth through the receiving instruments. Electric storms and auroral displays apparently greatly heighten these effects. These noises are of varying character, and Mr. J. J. Carty well describes them in saying:

Effect of charged clouds or auroral displays on telephone.

"'Sometimes it sounded as though myriads of birds flew twittering by; again sounds like the rustling of leaves and the croaking of frogs could plainly be heard; at other times the noises resembled the hissing of steam and the boiling of water.'

J. J. Carty on strange noises heard in the telephone.

"The noises due to these natural phenomena, whatever their true cause may be, are chiefly annoying on long lines, short lines being disturbed only during heavy electrical storms. This is not the case, however, with the noises arising from the proximity of other wires carrying varying currents. Telegraphic signals can be plainly heard in a telephone instrument on a line running parallel with a neighboring telegraph line for a very short distance. The estab-

lishment of an electric railway or electric lighting plant in a town using grounded telephone lines will always cause serious noises in the telephones, and if the lighting current is alternating the use of the telephones is usually out of the question at night time while the plant is running.

Telephonic noises due to street-cars.

"Disturbances on telephone lines from neighboring wires may be attributed to one or all of the following three causes: leakage, electro-magnetic induction, and electro-static induction.

"Leakage may occur through defective insulation between the two circuits; or even when the insulation of the wires themselves is practically perfect a heavy return current from a grounded circuit, such as of an electric railway, may, upon its arrival at the grounded end of the telephone line, have the choice of two paths, one through the telephone line, and the other a continuation of its path through the ground. This is the greatest source of trouble due to railway work, on grounded telephone lines. A strange fact in connection with this is that the noises in the telephones do not correspond with the fluctuations due to the commutator of the generator armature, as would be supposed, but to the movements of the armatures on the car motors. The tone in the receiver is an indication of the movements of the car, and variations in speed may be clearly noticed."

Telephone troubles due to electric leakage.

Some of the difficulties above referred to are present even in the case of metallic circuits; for example, the disturbances that occur from neighboring wires. It will be interesting, therefore, to inquire more particularly into their causes as well as into the means by which they may be avoided.

Cross-talk.

It sometimes happens that, during conversation with a regular correspondent, a faint conversation,

evidently between people that are not directly connected with the line, can be heard, sometimes with sufficient distinctness to be understood, and at other times only as more or less confused talk. These disturbances are generally known as "cross-talk," and, as suggested in the above quotation, may be due to any of the following causes: leakage, electro-magnetic induction, and electro-static induction. The troubles arising from leakage must necessarily exist in the case of all grounded telephone circuits. They may even exist in the case of metallic circuits, unless considerable care is taken in the insulation of the lines. Cross-talk arising from electro-magnetic and electro-static induction can generally be practically obliterated by the use of metallic circuits, provided certain precautions are taken, which will now be referred to.

Causes producing telephonic disturbances.

The actual amount of electro-magnetic and electro-static induction that can be produced in any telephone circuit from the influence of neighboring wires is very small. It might appear, at first sight, therefore, that at the best the amount of such disturbances must be slight. This, however, is far from being the case, for the delicacy of the telephone is so great that an almost inconceivably small amount of current is sufficient to produce clear and intelligible speech in the receiver. Take, for example, the case of the telephone in the desk set represented in Fig. 60. A definite amount of mechanical energy must be expended in raising the receiving telephone from its supporting hook on the switch lever. Assuming the weight of the receiving instrument to be say 13 oz., and that it is raised through a vertical distance of one foot in order to bring it to the ear of the party listening, then if all this energy were converted into electric energy, so marvellously

Almost inconceivably small amount of electric energy required to make the receiving telephone talk.

small is the amount of current required to produce clear and intelligible speech in the receiving telephone, that the electricity so generated would suffice to keep the receiver continually sounding for some 240,000 years!

Electro-static induction principal cause of telephonic cross-talk.

It was at one time believed that the principal cause of "cross-talk" was due to electro-magnetic induction. Investigations, however, undertaken by J. J. Carty, would appear to show that electro-static induction is the principal cause.

Protective influence of lead-covered cables.

As far as electro-static induction between two neighboring wires is concerned, its effects may be completely avoided by placing the conductors within lead-covered sheaths. In such a case any charge communicated to either of the wires will terminate on the outside of the conducting sheath, and so will fail to charge the conductors placed inside. Where bare wires are employed, as in the case of overhead conductors, some method must be employed to avoid the effects of electro-static induction. Since the disturbances due to heavy currents employed in arc and incandescent lighting and in power circuits are mainly due to electro-magnetic induction, it is desirable to employ some method that will protect the wires from disturbances produced by both types of induction. This is accomplished by what is called the transposition of the circuit.

The transposition of telephonic wires, or telephonic cross connection, as it is frequently called, is an arrangement of the circuits for the purpose of lessening the effects of induction by crossing equal lengths of adjacent parallel wires, so that they alternately occupy opposite sides of the circuit. In this manner the effects produced by opposite sides of the

circuit wires neutralize each other. The transposition of the conductors is effected by means of insulators provided with two grooves, as shown in Fig. 61. Here, as will be seen, the two circuit wires, instead, however, of proceeding as usual, in one and the same straight line from the end of one pole to the next pole on the line, are "dead ended," or connected to the insulators on open circuits, in the manner shown in the figure. Small cross wires are then employed, one of which connects *a* with *d*, and the other *b* with *c*, so that the wires cross over or are transposed at these points.

Transposition of telephone circuits.

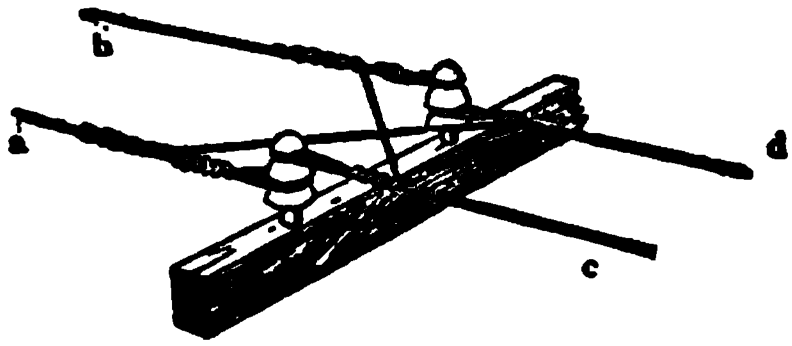


FIG. 61.—Transposition of Overhead Telephone Wires. Note the two grooved transposition insulators and how the line wires are transposed by their use.

In practice transpositions are made every quarter or every half mile. Where, as is practically always the case, a great number of separate telephonic circuits are suspended on the same pole line, no two sets of separate conductors that run side by side have their separate wires transposed either at the same pole or the same number of times, since, were this done, although their circuits might be non-inductive as regards their own wires, yet they might badly influence neighboring circuits. This difficulty is avoided by making the number of transpositions twice as great in one circuit as in the neighboring circuit. By twisting outgoing and incoming conductors together, a perfect system of non-interfering circuits is obtained. This method is always adopted in the construction of telephone cables.

Number of telephonic cross connections per mile.

In telephone cables, where a great number of separate pairs of wires are employed, the separate circuits are insulated, and each pair of conductors are twisted together and placed inside a lead sheathing. Here the lead is slightly alloyed with tin, in order to decrease its tendency to corrode. In the early history of telephony, rubber was employed for the insulating substance; but while this substance answered admirably so far as its insulating powers were concerned, it was found in practice that its electro-static capacity was so great that it has been replaced by some other insulating substances; for, an increase in the electro-static capacity of a telephone wire decreases the delicacy of its operation. In order to obtain the comparatively low electro-static capacity possessed by air, dried paper has been employed for the insulator between individual pairs of conductors. At first this paper, coated with paraffine, was aërated with dry carbonic acid gas. Now, however, dried paper alone is preferably used, the conductors being either separately wrapped with a spiral of paper, or the two wires placed parallel to one another, with a sheet of paper between them, and each pair of wires being then twisted together. In this way the electro-static capacity of the telephone line has been greatly decreased.

Why rubber is objectionable as insulating material for telephone cables.

Paper-insulated telephone cables.

Telephone cables are either strung on poles or placed in underground conduits. When hung on poles, since the lead cover employed is too heavy to support its own weight, it is suspended from a steel wire or rope, called a messenger wire, tightly stretched between poles, and the cable supported on the messenger wire by means of a cable hanger. A cable hanger consists of a hanger and hook, connected with the cable in the manner shown in Fig. 62, the hook, H, being supported by the messenger

Messenger wire.

Cable hanger.

wire. A lead-incased, paper-insulated telephone cable, such as is employed generally by the Bell Telephone Company, is shown in Fig. 63.

FIG. 62.— Cable Hanger for Overhead Telephone Cable. Note the great number of separately insulated telephone wires placed within the lead covering of the telephone cable.

Cable terminal or cable box.

Where overhead wires are connected with underground cables, or the reverse, some special provision

FIG. 63.—Lead-incased Paper Telephone Cable. Note the fact that the separately insulated wires are here first insulated by a wrapping of some insulating material and then covered with the lead.

is necessary in order to prevent moisture from entering the cable, and thus injuring its insulation. This

Special terminal pole.

is done by means of a water-tight box, called a cable terminal or cable box. The terminal or box is generally formed of iron, and is supported on a special pole provided for the purpose. The cable enters the box either from above or below, through a brass tube or sleeve, that tightly fits the cable

FIG. 64.—Cable Terminal or Cable Box and Pole.

sheath, to which it is soldered by a wiped joint, such as is generally made by plumbers. Such a cable box, placed on a pole and provided with a platform for convenience in arranging the wires, is shown in Fig. 64, where an underground cable is connected with a pole line. Each metallic circuit, or each pair of separate wires, is spread out (fanned

out) to the separate terminals provided inside the box and arranged as shown in Fig. 65, which represents the inside of a cable box. The terminals of each of these circuits pass through insulators in the box, the openings being carefully

Interior of cable box.

FIG. 65.—Interior of Cable Head or Box.

made water-tight. Fuses and lightning arresters are placed between the circuits of the line and the instruments, in order to ensure protection from lightning discharges or other abnormal currents. Sometimes a cable box is made in a circular form, and placed on the top of the pole. In such cases the separate circuits are arranged around the cir-

cumference of the crown. In all cases, a waterproof, metallic cover is placed on the outside of the box, after a piece of lime has been placed inside for the purpose of absorbing moisture.

Lightning arresters for overhead lines.

Various forms of lightning arresters are employed on telephonic circuits. The protection of such lines from high-pressure lightning discharges or other abnormal currents presents many difficulties in actual practice. A very common form employed for the protection both of telephonic and telegraphic lines from lightning discharges is shown in Fig. 66. Here the line wires, A and B, are con-

FIG. 66.—Comb Lightning Arrester for Overhead Lines.

nected with the two line plates that are continuations of the lines at C and D respectively. These plates are provided with points, and are placed near a third plate that is connected to the ground by means of the wire G. The three plates are insulated from one another. Should lightning strike the line wire it will jump between the plates in the air gap between the points and the ground plates, and so pass to ground, rather than overcome the impedance of the instruments and coils on the line. The three plug-holes represented between the plates are for the introduction of a metallic plug, shown in the middle of the plate connected with the ground wire G. The insertion of this plug in either of the

holes between the line plates and the ground plate, will short-circuit that particular plate with the ground. If placed in the hole between the two plates connected with A and B, it will short-circuit the instruments, and afford an excellent means of protection against lightning strokes. This use, however, is highly objectionable, since a failure to remove such plug will, of course, put the line out of use, and, if this line be a party line, will punish others than the negligent subscriber who has failed to remove the plug.

Action of comb lightning arrester.

Another means frequently adopted for protection against either lightning strokes or the heavy currents employed on lighting and power circuits, consists in the introduction of a fine fuse wire in the circuit of each line conductor. This fuse wire generally consists of a very thin lead fuse, mounted on strips of mica inserted between metallic clips, and connected respectively to the line wires and the instruments that are to be protected. A difficulty arises in such cases in readily obtaining a uniformity in all the thin wires to ensure their blowing or fusing at the required and predetermined small increase of current.

Another form of lightning arrester is obtained by taking two blocks of carbon, and placing a thin strip of mica between them, these blocks being slipped in between spring clamps connected with the line wires. A lightning arrester consisting of both of these forms is shown in Fig. 67. Here a porcelain block is furnished with six metallic clips, four of which are vertical, and two horizontal. The line wires are connected with the two vertical clips on the upper right-hand side of the block, and blocks of carbon, with plates of mica between them, are con-

Double-pole lightning arrester with fuse wire.

nected with the horizontal clips on the lower left-hand side of the block. The fuse wires, supported on vertical sheets of mica, are placed between the line wires and the carbon blocks by connection with the vertical clips in the manner shown. The vertical binding post, placed between the two carbon blocks at the extreme left-hand side of the figure, is connected with the ground wire.

FIG. 67.—Double-pole Carbon Lightning Arrester, with double-pole fuse wires.

Under-ground conduits for telephone cables.

In the case of underground telephone cables, the cables are placed in conduits provided at suitable intervals with manholes, in order to readily obtain access to the cables, and to provide for drawing them through the ducts. In order to lessen friction in the introduction or removal of the cables, the ducts between successive manholes should be made as straight as possible. The conduits are made of various forms. Creosoted wood or vitrified terra-cotta is frequently employed. The latter has been found in practice preferable.

Advantages of copper over iron telephone wires.

The circuit wires for overhead lines are made either of copper, iron, or aluminium. Since the distance between successive poles of an overhead line will necessarily depend on the tensile strength of the wire, iron possesses a slight advantage over copper so far as first cost of construction is concerned. In other respects, however, it is vastly inferior to copper; for, the most important property

of a line wire is its conducting power, and, as we have seen, in order to make the conducting power of iron equal to that of copper, it would require the iron wire to have an area of cross-section nearly seven times that of the copper. This would necessitate a marked increase in the electro-static capacity of the iron conductor, which, as we have seen, is a serious objection. The resistance of the line wires or conductors for such circuits is conveniently measured in terms of what is called their weight-per-mile-ohm, or the weight of a conductor one mile in length, and of such a uniform area of cross-section as would give it a resistance of one ohm. Here, of course, the smaller the weight-per-mile-ohm, the greater will be the conductivity of the conductor.

Galvanized overhead wires.

Since iron wire corrodes rapidly when exposed to air, it is necessary to protect its surface in some way when used for overhead conductors. One of the best means for doing this consists in coating the wire with zinc or galvanizing it. The following method is proposed by Miller, to determine whether or not a sufficiently thick layer of zinc has been placed on the wire during the galvanizing process: Select several samples of the wire at random, and immerse them in a saturated solution of copper sulphate for 70 seconds each. Then remove the wires and wipe each clean with a cloth. Repeat this four times. If, at the end of the fourth immersion, the wire appears black, as it did at the end of the first immersion, the zinc has not all been removed, and the galvanizing has been properly effected. If, however, the wire has a copper color, either over its entire surface, or in parts, it shows that the zinc has been eaten away, and that the coating of zinc is insufficient. The wire should, therefore, be rejected.

CHAPTER IX

TELEPHONE SWITCHBOARDS. CENTRAL STATIONS

"Nothing is more important to the telephone exchange manager than the switch-board. It is, as it were, the central sun, around which all his other apparatus revolve."—*Practical Information for Telephonists:* THOMAS LOCKWOOD

THE object of the telephone is to be able to communicate with a number of different people in various parts of a city or various sections of country. In order to be able to do this, some form of telephone exchange or central station must be employed, by means of which any subscriber or telephone user, who is connected with a system, can be placed in direct communication with any other subscriber or telephone user connected with the same system. In order to do this, all the various telephone lines, that are either metallic or grounded, radiate in various directions from the exchange or central station to the different subscribers. At the central station all these wires are connected to a form of apparatus called a switchboard.

Necessity for central telephone station.

Since, in a metallic circuit, a double set of line wires pass from each subscriber to the switchboard at a central station, these, together with the wires necessary for the operator to receive and answer calls, and to connect various subscribers together, make such a switchboard an exceedingly complex piece of electric apparatus. For the sake of simplicity, however, we will take the case of two subscribers only, in a small telephone exchange, and,

Part of a small telephone exchange switchboard.

in order to make the matter still simpler, will suppose the circuit to be furnished with ground-return conductors; that is, to have one end of the circuits grounded. Such simplified switchboard connections are shown in Fig. 68.

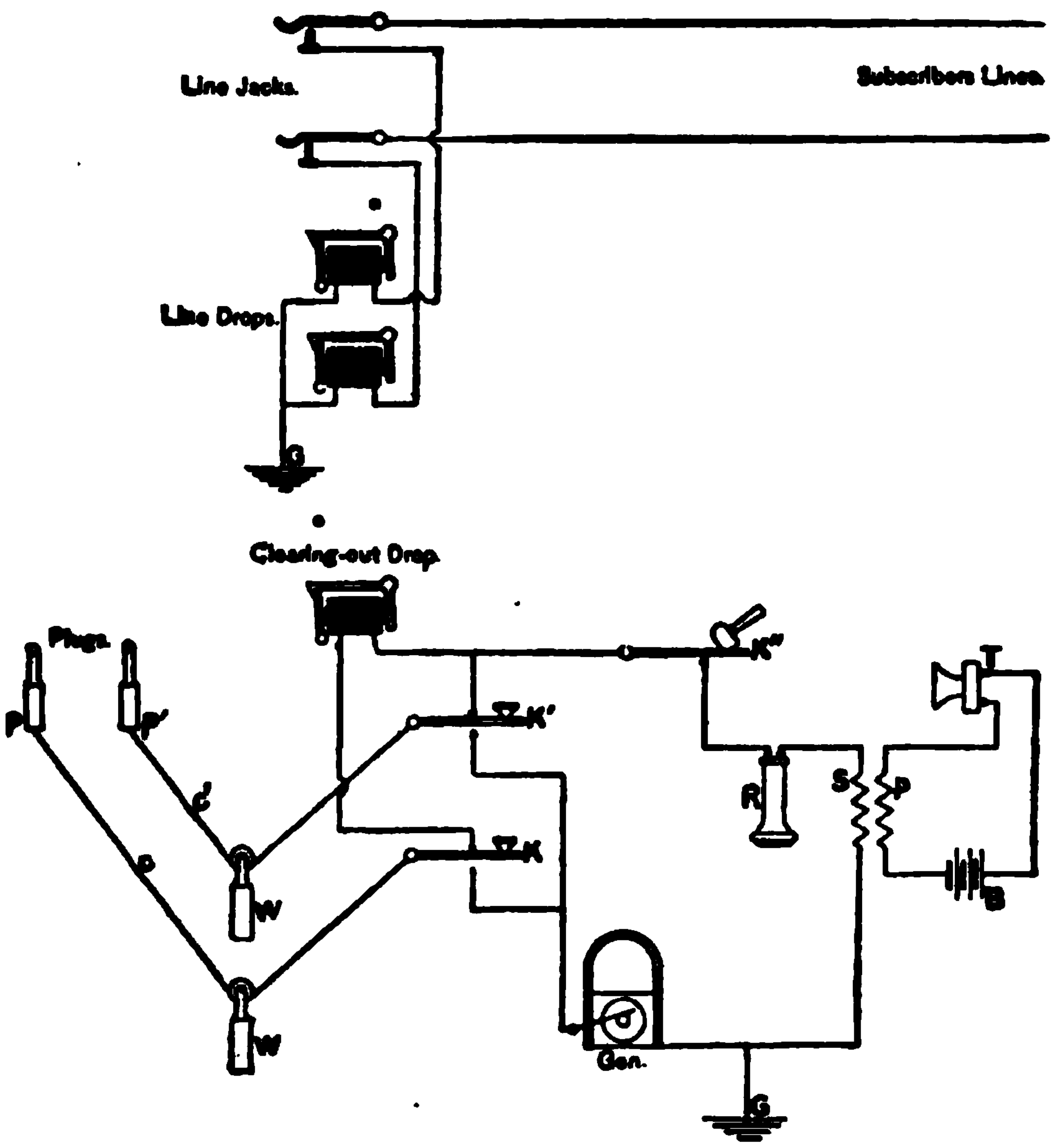


FIG. 68.—Part of a Central Station Switchboard for a small Telephone Station.

Two different subscribers' lines only enter the station, and are connected with what are called line jacks, which consist of a form of spring contact, placed back of the switchboard, and provided each with a hole immediately in front of the switchboard for the insertion of a plug connected with a cord circuit. A separate spring-jack is placed on the switchboard for every separate subscriber. The insertion of a plug into a particular spring-jack will connect the circuit of the plug with the line of that

Spring-jacks, plugs, cord-circuits, and line-drops.

particular subscriber. There is connected with each subscriber's line an electro-magnetic apparatus, called a line drop, which is provided for the purpose of calling the attention of the operator to the fact that a call has arrived from a certain subscriber's line, the particular line being indicated by the falling of a shutter, on which is displayed the number of the calling line. The release of this shutter is effected by the movement of the armature of an electro-magnet, through whose coils the calling current passes. The operator's receiver is represented at the lower part of the figure by R. Her transmitter T is placed in the local circuit of the battery B, and the primary *p* of the induction coil, whose secondary *s* forms a part of the circuit of the receiver R. Keys K, K′, K″, a magnetic generator, plugs P and P′, with their cords *c* and *c*′, weighted at W, W, are placed in the circuit of the secondary *s*, and connected to the ground at G.

Operator's apparatus.

Method of connecting subscribers at the two ends of a telephone circuit.

Supposing now that a call comes in over a subscriber's line, as indicated by the dropping of the shutter of one of the line drops or annunciators. The operator now takes up the plug P′, and inserts it into the particular line jack whose number corresponds with the number displayed on the line drop, thus connecting the circuit of the exchange with this line. Then, moving the lever of the key K″, so that its spring makes contact with the stop below, as shown in the figure, she thus connects her instruments with the circuit of the calling line, and listening at her 'phone, which, for the sake of convenience, is almost always held to her ear by a headband, she speaks into her transmitter, and asks "What number?" On learning the particular number desired, she now takes up the other plug P, and inserts it in the line jack of the desired number,

and thus completes the connection from the ground at the central station, through the generator, key K, cord *c*, plug P, and the particular line jack called for, with the calling subscriber. Should the operator desire to "listen in," so as to ascertain whether the subscribers have completed their conversation, she merely depresses the key K″, thus throwing her telephone into a branch circuit between the two subscribers. K′, when so desired, may be used to connect the generator of the line connected with the plug P′.

FIG. 69.—Switchboard Suitable for small Isolated Telephone Station.

Clearing-out drop or annunciator.

The clearing-out drop is an electro-magnetic apparatus similar to the line drop, which is employed in order to notify the operator when either of the subscribers is through with their conversation, or rings off; that is, sends a current from the generator through the coils of the magnets, thus causing its shutter to drop.

Switch-board for small isolated telephone station.

A metallic circuit switchboard is arranged practically in the same manner. Here, however, metallic-return is employed in place of the ground-return. Without going into further detailed de-

scription of the switchboard, it will suffice to call attention to the switchboard suitable for a small, isolated exchange, represented in Fig. 69. Although this switchboard differs in some respects from that described in connection with Fig. 68, yet it will show in general the manner in which such connections are carried out in the switchboard of Fig. 69. There are 100 line-drops or electro-magnetic annunciators *d, d, d, d,* arranged in ten rows of ten each. Below these are placed 120 spring-jacks *j, j, j, j,* arranged in six rows of twenty each. Immediately below the spring-jacks is a single row of ten drops, the clearing-out drops, that are only connected in the circuit when the two subscribers are connected for conversation. When the subscribers have completed their conversation, a current is sent from either end of the line through the coils of the clearing-out drop, thus indicating the completion of the conversation. In the particular case shown in the figure, the four pairs of cords, counting from the left, are so inserted in the jacks as to connect subscribers 5 and 78.

Clearing-out drops.

A somewhat similar form of switchboard is shown in Fig. 70. There are only 50 electro-magnetic drops placed in the upper part of the board, and 50 spring-jacks placed below them. Six pairs of cords connected with six annunciators, A, B, C, D, E, and F, are placed above the spring-jacks.

Self-restoring annunciator drops.

In the early forms of electro-magnetic drops it was necessary to reset the drops by hand. This required both time and attention on the part of the operator, and, therefore, decreased the number of subscribers that one operator could satisfactorily take care of. In later improved forms, the resetting of the drop is effected automatically by means of a

second electro-magnet, whose coil, called the restoring coil, is placed in a local circuit containing a battery, and this circuit is closed by the insertion of the plug into the jack of the line belonging to that drop.

In another form of signal, which is coming into general use, especially in large stations, the electro-

FIG. 70.—Private Exchange Telephone Switchboard.

magnetic drop is replaced by a small incandescent electric lamp, which lights up on the arrival of a call from a distant station, thus notifying the operator that connection is desired. Similarly, the extinguishment of such a lamp indicates that the conversation is over. Such signals are called luminous signals. These are found in practice to be much more satisfactory than the electro-magnetic signals.

Luminous telephone signals.

Their advantages arise from many causes. In the first place, the luminous signal attracts the attention of the operator with much more certainty than does the electro-magnetic drop. Then there is no mechanism, as in the case of the electro-magnetic signal, that requires careful adjustment, and which is liable to cause trouble if not carefully looked after. Moreover, luminous signals are automatic in their action. The lamp continues to burn only as long as the current is passing through it, thus possessing the marked advantage over any other form of self-restoring drop, of being instantly reset when the current is cut off. But what is, perhaps, much more important than all, is the fact that such signals can be made to occupy a very small space on the face of the switchboard, an extremely important consideration in the case of switchboards for large stations. Among still further advantages which luminous signals possess, may be added that, by making the lamps of different colors, it is possible to convey to the operators some information other than that certain subscribers desire connection. Then again, such signals, when broken or inoperative, can be almost instantly replaced, which is far from being the case with the circuit connections of the electromagnetic drops. Finally, luminous signals are cheaper to install.

Advantages of luminous telephone signals over electro-magnetic annunciators.

We have already referred to the type of incandescent lamp suitable for switchboard work on telephones. For effective action it is necessary that such lamps should be well made and of a uniform resistance. Abbott shows that, in the case of well-constructed telephone signal lamps, the average life is about 12,000 hours. Of course, the length of time that, in most cases, such lamps are in actual use is short, so that the number of times that an

Incandescent lamps for telephone switchboards.

individual lamp can be operated is frequently very great. A case is cited in which a particular telephone signal lamp, although flashed over a million times, yet did not show any serious signs of old age.

Wherever the number of subscribers on a switchboard is greater than a single operator can take care of, it is necessary to provide a switchboard of a greater capacity, arranged for several operators. If two operators can readily handle all the subscribers, then a switchboard of greater width is provided, and two operators are placed before it, each being furnished with the necessary transmitting keys, switches, and generators. When necessary, either of these operators can reach across the other, so as to be able to insert her plugs into distant jacks. In this manner it is possible for the two operators to take care of, say, 500 separate subscribers.

How subscribers up to 500 are handled.

But where the number of subscribers exceeds 500, then some other plan must be adopted. Since the breadth of such switchboards would necessarily be too great to enable a distant operator to reach over so as to insert her plug in the most distant jack, and, moreover, since the length of such plug cords would be inconveniently great, too great, indeed, to be readily disposed of in the space between the table and the floor, a form of switchboard called a multiple switchboard must be employed.

Multiple switchboards for telephone stations.

Multiple switchboards for central telephone stations are designed to enable each operator to make any connection that may be desired without the aid of any other operator, and without the use of unduly lengthy cords. The multiple switchboard is divided into a number of separate sections, each of which affords working room for three operators. Each section is provided with a separate spring-jack

General arrangement of multiple switchboards for central telephone stations.

for every subscriber connected with the line, so that in a station of, say, 3,000 subscribers, there would be 3,000 separate line-jacks in each panel. The number of line-drops or visual signals in each panel, however, is limited, say, to 200, so that a multiple switchboard for 3,000 subscribers would require 15 separate panels. An additional jack, called an answering-jack, however, is provided for each line that has a drop or a luminous signal at that particular section, these jacks being placed in a separate panel, generally at the lower side of the board.

Suppose now, in the case of such a 15-panel, 3,000-subscriber, multiple switchboard, a call comes in from a distant subscriber. His drop or luminous signal will be operated at one only of the 15 separate panels. The operator at this panel at once inserts an answering plug in the answering-jack of that line, and then inserts her telephone into the cord circuit of that plug, and inquires the particular number desired. She then completes the connection with the particular number called for by inserting a calling plug into the particular multiple-jack of that subscriber's line, which will, of course, be situated in her section. During the hours of the day when the number of calls is small, a single operator can easily take care of all the calls on her section, but, as the number of calls increases, two, and in the busiest hours of the day, three operators are placed at each section. Although a single operator can readily reach all the jacks on a single section, yet, since three operators are stationed before a single section during very busy hours of the day, each operator is generally provided with a multiple-jack for all the lines within her reach.

Manner of operating a multiple switchboard.

A test employed on multiple switchboards, called

the busy test, is necessary in order to prevent the connection on any of the separate panels of a subscriber who has already been connected with another line, by ascertaining whether the particular line called for is free or not. This test consists in some means whereby an operator at any panel can almost instantly ascertain whether a particular party called for is or is not already connected with another subscriber. There are various means by which such a fact is readily ascertained.

Busy test for multiple switchboards.

It is an extremely expensive matter to increase the number of subscribers on a multiple switchboard beyond a certain limit. In large exchanges, where the board may be connected with, say, some 6,000 subscribers, there would be required 30 separate sections, each of which would contain, say, 200 electromagnetic annunciators or signals for the 200 separate line wires connected with such sections. If an additional section, containing, say, 200 separate, additional lines, annunciators, signals, etc., be added, the increased cost does not stop with such increase; for, besides the apparatus required for the new section, there must be added 200 multiple-jacks to each of the already existing sections. It is for this reason, therefore, that in case of exceedingly large switchboards, some other system is often employed. Such a system, called generally a transfer system, depends for its operation on the abandonment of multiple-jacks, and in employing two or more operators to make connection between two subscribers whose lines terminate on different sections of the switchboard. For this purpose lines called trunk lines are employed.

A possible limit to size of multiple switchboard.

Trunk lines and transfer systems.

The general appearance of a multiple switchboard, such as is required for use in a large central

Multiple switchboard for large central telephone station.

telephone station, is represented in Fig. 71. The photograph was taken just before the switchboard was placed in actual use, and while the operators were, therefore, away, so as to enable the details of the exterior to be more readily examined. In Fig. 72, another form of multiple switchboard; *i.e.*, that employed at the 34th Street Exchange, New York City, is represented, with the operators at work in answering calls, making connections, etc. In

FIG. 71.—Multiple Switchboard for Large Central Telephone Station. Note the great number of spring-jacks in each of the separate panels and the line drops or visual signals connected with each of such panels.

all such stations a chief operator is installed at a separate desk, so provided with apparatus that she can readily communicate by 'phone with any of the operators.

Party lines for telephonic communications.

We have described all telephone lines so far as if there were only two parties, or, including the central station, three parties on such line, or, in other words, only two regular stations on the line. Such

lines are called private lines. Sometimes, however, lines called party lines are employed, in which more than two separate stations are situated on the same line. Party lines may be so arranged that either a code or audible signals are employed, so that only one of the several parties on the line will go to the 'phone when called; or, they may employ some system of selective signalling, one subscriber being

Fig. 72.—Multiple Switchboard for Thirty-fourth Street Telephone Exchange, New York City.

called without disturbing the others. Systems in great variety have been devised for party-line telephones.

Trunk telephone lines for long-distance work.

In all large telephone stations, where lines connect the telephone system with distant cities, means must be provided by which it is possible for any subscriber connected with a multiple switchboard in such distant city, to be connected with any subscriber connected with the multiple switchboard at that particular station. This is accomplished in various

ways, the operators being placed in communication by trunk-line wires with the particular long-distance system of the city calling the local exchange.

Difficulties in long-distance transmission.

As the distance between telephone stations increases, unless care is taken, difficulties are experienced in obtaining clear and intelligible speech. These difficulties arise from the impedance of the telephone line, or from the failure of the receiving instrument properly to reproduce the tones of the voice. The difficulties arising from attenuation are remedied by decreasing the impedance of the line. Impedance arises from a variety of causes.

Causes of impedance on telephone lines.

In the first place, impedance is due to the ohmic resistance, which depends on the character of the conductors employed, the area of their cross-section, and their length. Where the telephone lines are long, the resistance must, therefore, be decreased as far as possible by employing fairly heavy copper wires.

Another cause of impedance is what is called the insulation resistance of the line, that is, the resistance measured either between each line and the ground, or between the two lines of a metallic circuit. The higher this insulation resistance, the smaller will be the leakage. It has not been found to be an advantage, however, to ensure too high an insulation resistance. On the contrary, a certain amount of leakage is of advantage to long-distance transmission. Of course, too great a loss of current would cause the current received at the distant end of the line to be too feeble to produce intelligible speech. There is, indeed, for every line, a certain relation existing between the value of its insulation resistance and other electric values, by which the best results as regards long-distance transmission can be obtained.

TESTING CONDITION OF RAILROAD TRACK BY ELECTRICITY

Electrical and mechanical devices in Dudley's Dynagraph car automatically trace curv
on a moving strip of paper which show minutely the condition of the track over which t
car passes. The Dynagraph also marks the rails with paint at every uneven pla

The impedance of telephone lines is also affected by the electro-static capacity of the line, that is, the power of the line to act as a Leyden jar or condenser. Since, by this action of the line, its charge is held in position by the attraction of the opposite charge, the electro-static capacity of a line retards the currents, and prevents them from moving rapidly from one end to the other. The electro-static capacity of a line is increased by bringing the conductors near together. For this reason the circuits of telephone cables, where the wires are necessarily near each other, have generally a marked electro-static capacity. Finally, the inductive capacity of the line, or, as it is sometimes called, its electro-magnetic capacity, will also greatly influence its impedance.

Opposite effects of electro-static and electro-magnetic capacity.

Fortunately for long-distance transmission, the ill effects produced by an increase in the electro-static capacity of a telephone line act in the opposite direction to the effects produced by electro-magnetic induction, so that it is possible so to construct telephone lines that the two opposite influences may nearly completely neutralize one another. Houston and Kennelly, in their work on the "Electric Telephone," thus speak of this balance of long-distance lines:

Houston and Kennelly on the balance of long-distance telephone lines.

"The effect of electro-magnetic capacity in the line, that is to say, between the parallel conductors forming the circuit, is not necessarily prejudicial to the development of telephonic current strength in the receiver. If electro-static capacity were absent from the line, then electro-magnetic capacity or inductance would be as detrimental to current strength, as it is when developed in the receiving apparatus, but being associated with electro-static capacity along the line, the influence of the one is

opposed to the influence of the other, and, when properly adjusted, they can be caused largely to neutralize each other.

"The total impedance of a long telephone circuit is, therefore, much less by reason of its inductance than it would be if the inductance were absent, since every line necessarily possesses electro-static capacity. In overhead lines, and especially in cable conductors, the electro-static capacity is greater than is needed to balance the electro-magnetic capacity, so that it is generally advisable to increase the inductance of the line when very long-distance transmission is desired. This is best accomplished by spreading the wires further apart on the cross-arms of the poles, so as to increase their electro-magnetic capacity, while at the same time reducing their electro-static capacity. In the case of cable conductors, the electro-static capacity is so far in excess of that required to produce the lowest impedance, in conjunction with the electro-magnetic capacity, that it might be advantageous to insert coils of wire at intervals in the circuit for the purpose of increasing the effective magnetic capacity. It is theoretically possible so to balance the conductor resistance, and conductor leakage, with the electro-static and electro-magnetic capacities, that the circuit will only offer a certain minimum impedance to a telephonic current, which will not distort or affect its frequencies differentially. But at present it is impossible to produce conductors which will combine these constants in the proper proportions to effect this result."

Inductance may balance electro-static capacity.

Where coils are of advantage in circuit.

Where the necessary balance has been obtained between the electro-static and the electro-magnetic capacities of a telephone line for any particular case, care should be taken that this balance is not destroyed. In the case of long-distance telephony,

where, in order to make the necessary connections, a grounded telephone circuit must be connected with the metallic circuit of the long-distance telephone, such a connection is not made directly, but indirectly, by means of what is called a telephone repeating coil. This coil consists of a particular form of induction coil, the primary and secondary of which have the same number of turns of wire. Since these wires are of the same diameter and length, the resistance of the primary is equal to the resistance of the secondary, so that the repeating coil does not produce any change in the E.M.F.'s of the currents, but simply acts to transfer inductively any variations that may exist in the currents in one circuit to the other circuit, thus repeating into one circuit any-

Nature and use of the telephone repeating coil.

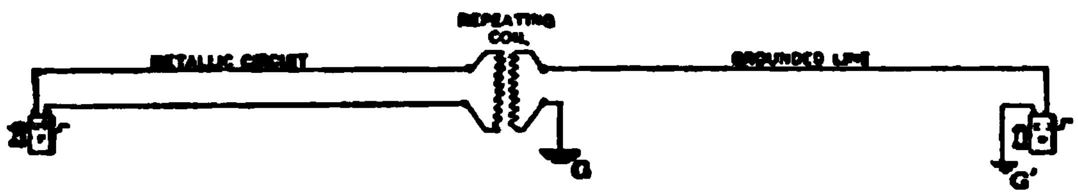


FIG. 73.—Circuit Connections of Metallic and Grounded Circuits. Note that there is here only an inductive connection of the two circuits.

thing that is spoken in the other. Suppose, for example, that it is necessary to connect the metallic circuit represented at the left-hand side of Fig. 73, with the grounded circuit represented at the right-hand side. This is readily done through a repeating coil; for, if the metallic circuit is connected as shown with one side of the repeating coil, and the grounded circuit with the other side, any messages sent over either line are inductively transferred to the other without any necessity existing to ground the metallic circuit.

During the past few years a great improvement in central-station telephone systems has been made by doing away with the local batteries and calling generators, and replacing them by a single common battery or source of electric energy. Such a system

Common-battery telephone system.

is called a common-battery system or central-energy system, and has been found in practice to possess many advantages over the old system.

T. C. Martin, in a report on electrical apparatus and supplies, prepared as the Expert Special Agent for the 12th Census Bulletin of the United States, thus refers to the matter of telephone switchboards in large central stations:

Martin on telephone systems and apparatus.

"In the modern common-battery system, to describe the method in broad terms, when the subscriber takes his receiver off the hook of his wall or desk set, a lamp lights up automatically on the section of the switchboard in front of the operator at the central office, in whose care his number happens to belong. When the operator sees this signal, she inserts a listening plug into the spring jack of his line, ascertains his wants, and then connects him with the spring jack of the subscriber wanted by means of a second plug connected with the other, the called subscriber being signalled by the magneto bell at his station. The flashing in and out of the lamps notifies the operator as to the fact that conversation is going on, and informs her when to withdraw the plugs that have connected the two together. Further refinements of this process arise from the grouping of subscribers in any large city into various branch exchanges and the employment of 'trunk' lines and 'trunk'-boards, but in its essentials the method remains the same, involving, however, the employment, with relays, of additional controlling and assisting apparatus.

"In connection with the boards at which sit the operators for the duty of putting subscribers directly into communication, each large exchange has usually a number of auxiliary switchboards. The line cables from outside, bringing into the central office

the various wires which lead to the switchboards, terminate in cable heads from which, in the interior cables, the wires are led to distributing boards, on one side of which the line cables end, and from the other side of which the wires in switchboard cables are led away to the main switchboards. Thus, lines from any outside cable can be led to any section of a board and given to any operator's care, permitting great ease in grouping subscribers according to the busy character of a wire or the work arising in regard to it. At this distributing point, moreover, the manufacturers introduce the lightning arresters, intended to protect any line from the bad effects of stray currents from outside and of lightning stroke itself. The general idea of all this apparatus is the same, but it differs greatly in manufacture. Another part of the work is the manufacture of the subsidiary boards for an exchange, to be used by monitors, wire chiefs, superintendents," etc.

Auxiliary and subsidiary telephone boards.

In the various forms of the switchboards above described, the different connections required by the subscribers are made, as we have seen, by operators at the central station. Such boards are called manual switchboards. There are, however, various systems by means of which it is possible for the subscribers themselves to make the connections and disconnections required. Such boards are called automatic switchboards. They are too complex, however, to be described in the limited space at our command.

Automatic telephone switchboards.

It is possible in telephony, as in telegraphy, to simultaneously transmit several messages over a single wire. Such systems, however, have not as yet come into general use, and, therefore, need not be described.

CHAPTER X

SOME CURIOUS FORMS AND APPLICATIONS OF THE TELEPHONE

"The salient feature in this discovery is the production of motion and sound, by the stylus of the Bain telegraph instrument, without the intervention of a magnet and armature. By the motion thus produced, any of the ordinary forms of telegraph printing or sounding instruments or relays may be worked. More than this, the apparatus operates in a highly effective manner under the weakest electric currents, rendering it possible to receive and transmit messages by currents so weak that the ordinary magnetic instruments fail to operate, or even to give an indication of the passage of electricity."
—*Electricity and the Electric Telegraph:* PRESCOTT

Possible simplicity of telephone circuits.

IF ALL systems of telephonic communication required the exceedingly complex apparatus described and illustrated in connection with various forms of switchboards, especially those employed in large central stations, the telephone would necessarily be limited in its use to cases where a great number of calls would require to be made over a carefully established line connected with some central station. Such, however, is far from being the case. Where it is necessary to establish communication between two ends of a long line so as to permit conversation to be carried on between two people only at its opposite ends, very simple arrangements will suffice. A line wire can readily be run for temporary use by laying an insulated wire directly on the surface of the ground. Indeed, for short distances, where a fairly strong battery is employed, the bare wire itself may be laid on the surface of the ground, although, of course, such a method would be extremely undesirable, and is not

to be recommended. As an instance of telephone circuits being established through conductors not erected for the purpose, we may cite the practice common in some parts of the West, where the long lines of wire fences are employed for telephone circuits, the ground being used as the return.

Sometimes, in military operations, the use of the telephone over temporary circuits is desirable. Of course, as a rule, important orders would never be delivered over a telephone wire, no matter how carefully such wire had been erected, or what precautions were taken to ensure privacy and secrecy in the despatch. Fatal blunders, that have occurred from misapprehension of orders, have led to an inflexible rule, in the British and some other armies, of never sending important orders except in writing. Still, cases may arise where a telephone communication temporarily established may afford considerable assistance in disclosing the position and the movements of the enemy. This would occur especially in the case of a balloon reconnoissance, where a light insulated wire, containing a metallic circuit, may be dropped to the ground, in order to ensure ready communication between an observer in the balloon and a correspondent on the ground.

Use of the telephone in balloon reconnoissance.

Another use of the telephone in military service has been made in the German army, in rifle practice. In order to give the soldiers practice which shall as nearly as possible represent what might occur during a real battle, the targets at which the men fire are made to appear and disappear at irregular intervals. In order to permit the commanding officer to determine both the positions and times of the appearances and disappearances, it is necessary to enable him readily to communicate with the

Employment of telephone in rifle practice.

men operating the signals. After employing different methods, it has been found in practice that the telephone affords the readiest and surest means of communication.

Method of laying temporary telephone cable.

The circuit required for the above purpose is readily established as follows: A cable, 500 metres in length, consisting of a pair of insulated metallic wires, is wound around a hollow cylinder, sufficiently large inside to hold the transmitting and receiving telephone. The line is rapidly laid as follows: The stations having been selected, one man takes the telephone out of the cylinder and attaches it to one end of the cable. Two other men then take hold of the reel and march quickly toward the other station. This being reached, they either connect their end of the wire with the other telephone taken from the hollow cylinder, or with the end of a second cable. This method permits the telephone line to be laid as rapidly as a soldier can march on a double-quick.

Use of telephones as receivers in systems of wireless telegraphy.

The wonderful sensitiveness of the telephone receiver, to which reference has already been made, leads to its use in a variety of apparatus as a means for detecting the presence of very feeble electric currents. It is for this reason that the ordinary receiving telephone is frequently employed as the most delicate receiver in systems of wireless telegraphy.

Hughes induction balance.

Another use of the telephone receiver as a delicate means for detecting feeble currents has been made by Prof. Hughes, in a piece of apparatus he calls an induction balance. This instrument was devised by Hughes, whose name has already been referred to in connection with the microphone, for the purpose of detecting the presence of metallic substances by the aid of induced electric currents. The general

arrangement of the apparatus is shown in Fig. 74. Four bobbins, A, B, C, and D, are wound with about 300 feet each of No. 32 copper wire (A.W.G.) and the coils connected, so as to form the two circuits represented. A and B are included in the circuit of a voltaic battery, and C and D in the circuit of a receiving telephone. In each case the distance between A and B is too far to permit any mutual induction to take place between them. The same is true as regards the distance between C and D. The coils are then placed in the position indicated in the

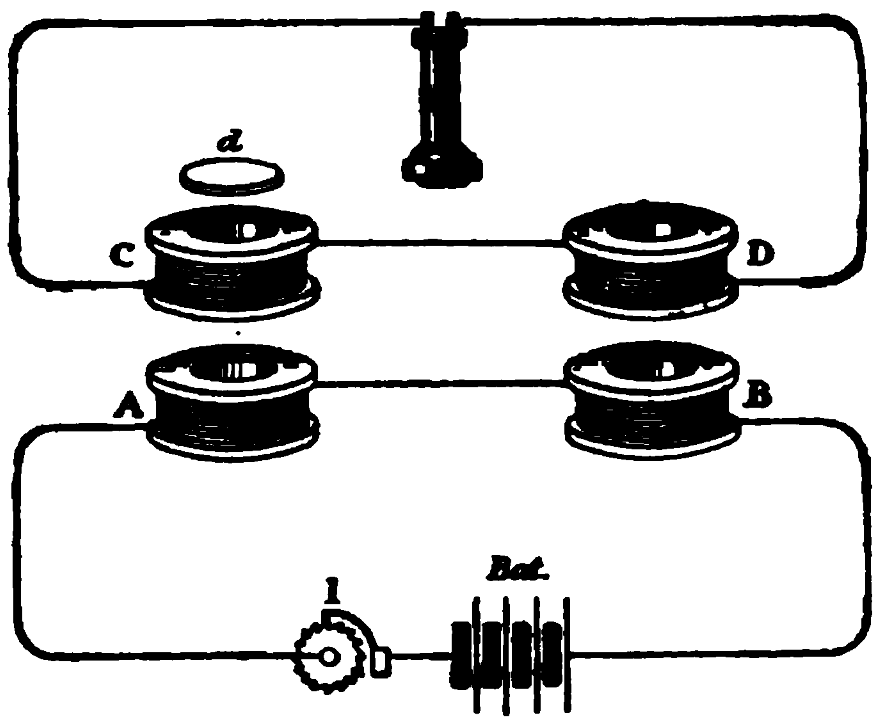


FIG. 74.—Hughes Induction Balance.

figure, so that C and D are directly above the coils A and B respectively. The connection between the coils is so made that the direction of the induction of A on C is opposite to that of B on D.

Under these circumstances, the coils A and B act as primaries to the coils C and D. A suitable interrupter I being included in the circuit of the battery and the coils A and B, on the rapid making and breaking of the circuit a noise will be heard in the telephone, but this can be caused to disappear by so adjusting the coils that the opposing secondary coils

Balance of opposite inductions.

produce but little noise, as can be readily done by adjusting a single pair of coils.

If now, under these circumstances, a small mass of metal, such as a coin, be interposed between either C and A, or D and B, or even if placed above one of the coils, as, for example, at *d*, the balance will be disturbed, and sound will again be heard in the telephone. This disturbance in the balance is due to the production of eddy currents in the mass of the coin. If, however, precisely similar metallic pieces be placed in similar positions between A and C, and B and D, no sound is heard. The wonderful sensitiveness of the induction balance is seen in the fact that the slightest difference either in the composition, size, or position of the coins will disturb the balance. For example, suppose two perfectly good and similar coins be so placed between A and C, and B and D, respectively, that no sound can be detected in the telephone. If now one of the coins be replaced by a spurious coin, so closely resembling the good coin in size and general appearance that the eye can not detect any difference, a noise will instantly be heard in the telephone. Even such slight differences as would be produced by hammering are at once detected, as are also such a slight decrease in the weight of a good gold coin as would result from its being clipped, that is, a coin from which a small quantity of gold has been unlawfully removed. Similarly, a sweated gold coin, that is, a gold coin which has been employed as a soluble anode of a plating bath, although only an exceedingly small quantity of the precious metal may have been removed, can be detected.

Delicacy of the induction balance.

Hughes audiometer

A similar form of apparatus, called the audiometer, was also devised by Hughes, for the purpose

of determining the delicacy of hearing of different individuals.

The submarine finder, designed for locating the position of metallic substances, such as torpedoes and other similar bodies, in deep water, is constructed on practically the same principles. A form of submarine finder is shown in Fig. 75. Here P, P′, are coils of insulated wire, inserted in a primary circuit containing a battery, B, and an interrupter, I. S and S′ are secondary coils inserted in

Construction and operation of submarine finder.

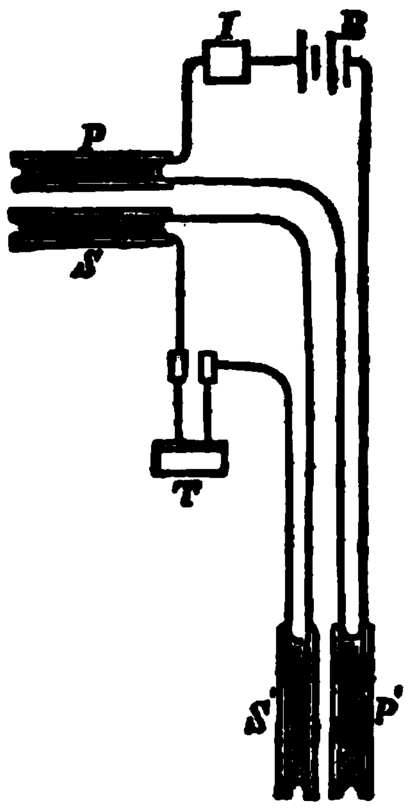


FIG. 75.—Submarine Finder for Locating Position of Torpedo. Note the resemblances between both the positions and the functions of the coils P, S, and P′, S′, and the coils A, C, and B, D, of Fig. 74.

the circuit of a telephone, T. When interrupted currents are sent through the primary circuit, the currents induced in the coils S, S′, neutralize each other by reason of their equal and opposite influence on the telephone. If, however, the instrument be lowered in the water, so that the coils P′, S′, are brought near a metallic mass, such as a torpedo, then sounds will be heard in the telephone, at first faint, but stronger and stronger as the finder approaches the submerged mass of metal.

No little difference of opinion exists among scientific men as to exactly what takes place in the diaphragm of the receiving telephone when it is in action. Where such diaphragms are made of thin sheet metal, there is no doubt that actual vibrations or to-and-fro movements occur that correspond to the sound waves spoken against the diaphragm of the transmitter. Indeed, no matter how thick such diaphragms may be, a to-and-fro movement of some kind is certainly caused under the influence of the changes that occur in the magnetism of the opposing magnet pole. But receivers have been successfully made in which the thickness of the diaphragm was so great that it would seem impossible to believe that it vibrated as a whole, and that, therefore, in such cases, instead of a mass movement of the diaphragm occurring—the diaphragm swinging to-and-fro like a drumhead—its to-and-fro movements were produced by the motions of its molecules.

Uncertainty as to nature of action of telephone receiving diaphragm.

Hughes made an extended series of observations on the action that occurs in carbon microphonic contacts, to determine whether or not the differences in the resistance of the circuit were due to the mass movements of the carbon pieces, or to their molecular movements. As a result of these investigations, he expresses his belief that, in the case of a particular microphone transmitter, consisting of a few blocks of carbon placed vertically over one another, and subjected to different pressures, the whole block of carbon increases and decreases in size from the result of the movements of its molecules. He asks how this increase in molecular size can result from the action of the sound waves, and he answers this question as follows:

Hughes's investigations on nature of motions of telephone diaphragms

"This may happen in two ways: first, by increased pressure on the upper surface, due to its enlargement; or, second, the molecules themselves, finding

a certain resistance opposed to their upward movement, spread themselves, making innumerable fresh points of contact. Thus an undulatory current would appear to be produced by infinite change in the number of fresh contacts. I am inclined to believe that both actions occur; but the latter seems to me the true explanation; for if the first were alone true, we should have a far greater effect from metal powder, carbon, or some elastic conductor, such as metallized silk, than from gold or other hard unoxidizable matter; but as the best results as regards the human voice were obtained from two surfaces of solid gold, I am inclined to view with more favor the idea that an infinite variety of fresh contacts brought into play by the molecular pressure affords the true explanation. It has the advantage of being supported by the numerous forms of microphone I have constructed, in all of which I can fully trace the effect.

Hughes on nature of telephone diaphragm motions.

"I have been very much struck by the great mechanical force exerted by this uprising of the molecules under sonorous vibrations. With vibrations from a musical box two feet in length, I found that one ounce of lead was not sufficient on a surface of contact one centimetre square to maintain constant contact; and it was only by removing the musical box to a distance of several feet that I was enabled to preserve continuity of current with a moderate pressure. I have spoken to forty microphones at once, and they all seemed to respond with equal force. Of course, there must be a loss of energy in the conversion of molecular vibrations into electrical waves; but it is so small that I have never been able to measure it with the simple appliances at my disposal. I have examined every portion of my room—wood, stone, metal, in fact all parts—and even a piece of india-rubber: all were in molecular

Marked energy of molecular vibrations.

movement whenever I spoke. As yet I have found no such insulator for sound as gutta-percha is for electricity. Caoutchouc seems to be the best; but I have never been able by the use of any amount at my disposal to prevent the microphone reporting all it heard."

Ader's membrane-less telephone.

This same question respecting the character of the movements of the diaphragm of the receiving telephone instrument has been investigated by Ader.

FIG. 76.—Ader's Receiving Telephone; an instrument capable of reproducing speech, although devoid of a membrane.

This gentleman constructed a receiving telephone with which he was able to receive intelligible speech, although the telephone receiver was provided with no part that could properly be regarded as a membrane. The instrument Ader constructed for this purpose is represented in Fig. 76. Here an iron wire, E, surrounded by a coil of insulated wire, S, wound on a quill, F, has its lower end soldered to a heavy piece of copper, K. The upper end of the wire passes through a thick wooden board, B, and

is bent at *e*, as shown. The ends of the coil of insulated wire are connected with the binding posts P and P′. Words spoken into the transmitter can be distinctly heard by placing the ear near *e*. Here there is no membrane, and the only conceivable way to account for the iron wire impressing on the air surrounding it the speech uttered into the transmitting instrument is by changes in its size, due to molecular movements.

Possible influence of the Page effect in the Ader telephone.

Referring again to the fact that marked changes of temperature occur between the points of contact of a microphonic transmitter, it is of course possible that the action of such differences of temperature is to produce a series of local expansions and contractions that follow one another in accordance with the variations in the strength of the current passing. In the case of the Ader membraneless telephone just described, the expansion of the whole mass of the iron wire may be due to such local expansions and contractions. There would appear to be but little doubt, however, that another explanation may be that changes occur in the length of the wire, due to its magnetizations and demagnetizations. It is well known that such changes of length actually take place, and Page, as already mentioned, has called attention to the faint sounds that are heard in a metallic wire when it is rapidly magnetized and demagnetized. It is interesting, however, to note, in this connection, that if the true action of the microphonic transmitter be due to local expansions and contractions, such a transmitter should be reversible, that is, should be able to act as a receiver. Hughes has, in point of fact, succeeded in making a microphonic transmitter so act as a receiving telephone.

In the form of a transmitter shown in Fig. 77, constructed by Dunand, we have a carbon micro-

phone transmitter, that is also capable of acting as a receiver and thus reproducing speech. This instrument consists, as shown, of two thin iron plates, A and A', supported by a wooden ring, so as to form a hollow box. Inside this box are placed two carbon disks, B, B, with a conically shaped piece of carbon placed between them. The proper adjust-

FIG. 77.—Dunand Carbon Microphonic Contact Telephone Receiver.

ment of the carbon contacts is ensured by turning a torsion screw, E, placed in connection with a metallic wire, wrapped around the conical piece of carbon.

Moncel, in his book on "The Telephone, Microphone and Phonograph," thus refers to his own opinion and to the opinion expressed by Prof. Fleeming Jenkin, as to the true nature of the action of microphonic contacts:

"Mr. Fleeming Jenkin writes to this effect in the

new edition of a treatise on electricity and magnetism. He observes that a singular fact has been discovered by several persons, who have ascertained that not merely non-magnetic and non-conducting bodies can be substituted for the diaphragm of receiving telephones, but that they will act without a diaphragm at all. In this case it is evident that we have to do with the sounds discovered by Page, and that they are produced by the magnet itself, in which each molecular movement constitutes the source of the sound produced. This sound becomes articulate as soon as its increase and decrease can follow the increasing or decreasing action of the voice which produces it at the sending-station. It is certain that when the transmitted currents are due to the action of the Bell diaphragm, the sounds due to the Page effects ought to correspond with those which would be given by iron diaphragms adapted to the receiving instruments; so that, when a telephone has an iron diaphragm, there are, in fact, two voices, that of the diaphragm, which is strong, and that of the magnet, which is weak. When a disk of wood is substituted for one of iron, it acts as a sounding-board for the Page effect, and when the disk is of metal, induction is developed by the magnetic modifications, and tends to produce vibration, thus developing a third source of sound, which may be called the Ampère effect. Finally, a fourth source of sound may result from the induced effects produced in the wire itself in consequence of changes in the intensity of current. These sounds, first observed by M. de la Rive, have since been studied by Mr. Fergusson, of Edinburgh.

Professor Fleeming Jenkin on the action of telephone diaphragms.

"Mr. Fleeming Jenkin's opinion only differs from mine in his ascribing the energy of sound acquired by a telephone with an iron diaphragm to the preponderance of sounds in the latter, whereas I con-

Wherein Jenkin and Moncel differ.

sider it to be chiefly due to the increase of energy in the whole magnetic system produced by the reaction of the two magnetic parts on each other. If the two effects could be taken singly, it is probable that the sounds produced by each of them separately would be similar, since in magnetic effects the reaction and action are equal. But as they are combined, it becomes difficult to assign to each the share which belongs to it in the general effect observed. Besides, it is quite possible that the sounds of the diaphragm may appear to be stronger and more distinct, because it is nearer to the ear than the magnet,

FIG. 78.—Preece's Thermo-telephone. Note the connection of the heated stretched platinum wire with the metallic diaphragm at one end through the ground and the battery and telephone to the other end.

and because the effects of magnetization and demagnetization are then more easily produced in consequence of the mass of the magnetic body being smaller."

Thermo-telephone.

A very curious form of telephone called the thermo-telephone, and capable of acting either as a transmitter or a receiver, is shown in Fig. 78. A stout piece of mahogany, A, serves as a base for the support of an upright, holding a disk, D, of thin sheet iron. A platinum wire, *pp*, attached to the centre of the iron disk, is connected to a post, C, that

is capable of sliding to-and-fro, and being fixed at a distance from D, so as to obtain a proper tension of the platinum wire. The ends of this wire are connected with the circuit of a battery, B, and a microphone transmitter, M. On speaking into the microphone transmitter, variations are produced in the current strength, which, passing through the stretched platinum wire, result in its alternate expansions and contractions, with consequent to-and-fro movements of the diaphragm D. One listening at D can, therefore, hear what has been spoken into M.

Professor Forbes's glowing-wire telephone transmitter

The tightly stretched wire is capable of being employed as a transmitter. This has been done by Prof. Forbes, who inserted a fine platinum wire in the circuit of a storage battery and the primary of an induction coil. The battery produced a current strength sufficiently great to raise the temperature of the platinum wire to incandescence. On speaking in the neighborhood of this wire, the sound waves rapidly passing across it in quick succession altered its electric resistance, and so produced changes in the current strength. These changes caused corresponding changes in the secondary circuit, and so reproduced in the receiving telephone placed in such circuit whatever had been spoken in the neighborhood of the glowing wire.

Modified form of thermophone.

Preece has produced the modified form of receiving thermophone shown in Fig. 79, where a platinum wire is wound in the form of a close spiral, and suspended from a cork inside a hollow glass tube. Any suitable form of microphone transmitter is employed in connection with this receiver. On speaking into the transmitter, the currents are modified by the speaker's voice in the usual manner. These currents, passing through the coil of platinum wire, produce expansions and contractions, which cause

the air in the tube to vibrate in accordance with the movements of the transmitter. Consequently, one listening at the tube can hear what is spoken. The sounds, however, are faint, though distinct.

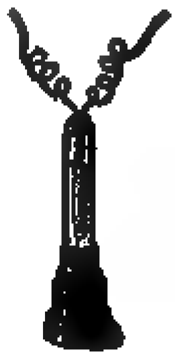


Fig. 79.—Modified form of Thermophone.

Diaphragm currents.

As we have already pointed out, differences of potential, and, consequently, electric currents called diaphragm currents, are produced when liquids are forced by pressure through porous diaphragms, or through capillary tubes generally. The converse of this is also true. If differences of electric pressure or potential be applied to liquids in capillary tubes,

Fig. 80.—Breguet's Electro-capillary Telephone. Note the small quantities of air that are contained between the membranes and the upper surfaces of the mercury in the glass tubes T and T_1.

Breguet's electro-capillary telephone.

they will cause the movements of the liquids through such tubes. Breguet has ingeniously applied these principles to the construction of an electro-capillary telephone. This instrument consists of two glass tubes, T, T_1, Fig. 80, nearly filled with mercury,

By courtesy of the "Scientific American"

TELLING HIGH FURNACE TEMPERATURES BY ELECTRIC PYROMETER

A glowing incandescent lamp in the tube of the Morse Thermo-Gage, shown, becomes more nearly white as its heat, and hence as the current through it, are increased. When it becomes the exact color of the furnace, the temperature of the latter is known, from the current through the lamp

whose lower extremities are drawn out in capillary points, and are plunged into two vessels, V, V_1, containing mercury, M, M_1, on the surface of which is acidulated water, A, A_1. The quantity of mercury in the vessels M, M_1, is such that the ends of the capillary tubes come near, but do not quite dip into, the mercury surface. Small platinum wires, P, P_1, and Q, Q_1, connect the mass of mercury in the two vessels and the two tubes respectively. While these wires are connected the level of the mercury is the same in each tube; but, if the wires are disconnected, and a battery is placed in the circuit of either tube, a difference will take place in its level, that will depend on the value of the difference of potential produced by the battery. But this apparatus is reversible. If, in any way, a difference of level is produced at either S or S_1, so that the mercury is caused to move in the tube, an E.M.F. and current will be thereby produced.

Differences of potential produce movements of the mercury column.

Suppose now, membranes, B, B_1, be stretched across the tops of the tubes T and T_1, thus enclosing a small mass of air between the membrane and the tops of the tubes at S and S_1, that the circuit wires be closed, and that one speaks in the neighborhood of either of such membranes. The sound waves, causing this membrane to vibrate, will cause the air below it to enter into vibration, and thus produce movements in the mercury column. These movements will produce differences of potential, and, consequently, electric currents. These currents, entering the other instrument, will produce similar movements in its column of mercury, together with corresponding movements in its diaphragm. Consequently, whatever is spoken in the neighborhood of one membrane can be heard in the other.

Movements of the mercury column produce differences of potential

Electrophorus telephone.

When a metallic plate is moved toward or from a charged electrophorus, a change will be effected in the distribution of its charge. If two such electrophori, D and C, Fig. 81, are placed at the ends of a conducting line, and a grounded metallic diaphragm is placed at B and A, near, but not in contact with, D and C, as shown, then we will have a form of

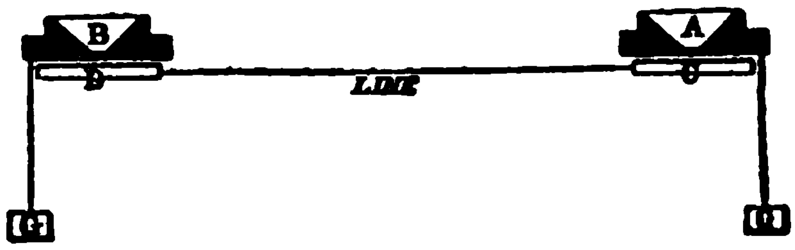


FIG. 81.—Electrophorus Telephone.

electrophorus telephone. If one speaks into the mouthpiece at B, its metallic diaphragm, being caused to move to-and-fro, will produce disturbances in the charges on both D and C, that will cause corresponding movements of the diaphragm at A. Consider, for example, a movement of B toward D. A greater charge will accumulate at the surface of D nearest B, thus decreasing the charge of C, and permitting the elasticity of its diaphragm to move it away from C. If, on the contrary, B moves away from D, its charge decreases, and a greater charge accumulates on C, thus attracting the metallic diaphragm toward it. In this manner, the to-and-fro movements of B produce similar movements in A, so that whatever is spoken into B will be repeated in A.

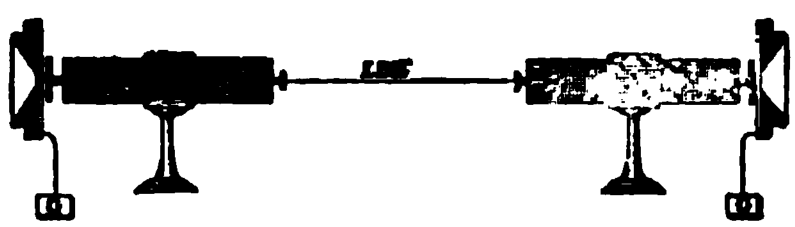


FIG. 82.—Dry-pile Telephone

Dry-pile telephone.

A similar form of dry-pile telephone is shown in Fig. 82. Here a De Luc dry pile, A, of 20,000 pairs has a grounded metallic diaphragm placed

opposite one of its poles. Its other pole is connected, by means of a conducting line, to one of the poles of a similar dry pile, B, that has its other pole placed opposite a similar metallic diaphragm, also grounded. Anything spoken into either diaphragm will produce disturbances in the charges that will enable the speech at one diaphragm to be heard at the other diaphragm.

It is currently reported, although we will not vouch for the accuracy of the statement, that Mr. Edison was at one time threatened with the loss of several of his telegraphic patents by a rival company, who fondly believed it had obtained what was practically a broad patent on the use of the electro-magnet for certain telegraphic apparatus. Edison thereupon set for himself the task of producing some mechanism operated by an electric current, that would be able to move the levers of telegraphic apparatus in a manner similar to the to-and-fro movements produced by the electro-magnet, and the action of an opposing spring. After trying various plans, Edison finally evolved a principle which is embodied in a form of apparatus called by him the electro-motograph. **Edison forced to invent.**

The electro-motograph depends for its operation on the fact that the friction of a platinum point against a rotating cylinder of moistened chalk is decreased by the passage of an electric current. The cause of this decrease in the friction is due to electrolysis. Its operation will be understood from an examination of Fig. 83, where a lever, A, pivoted at C, is furnished with a platinum point, F, resting on a strip of moistened paper, and held against it with some pressure through the action of a spring placed at S. The metallic drum on which the paper rests is rotated by clock-work. The tendency of the **Edison's electro-motograph**

paper to be carried forward in the direction in which the drum is moving is opposed by the action of a spring, R. A main battery, L, has its negative terminal connected with the platinum point F, and its positive terminal with the metallic drum G, through the telegraphic key K. A local battery, LB, is connected with a telegraphic sounding instrument through contacts at D and E.

Connections of electro-motograph.

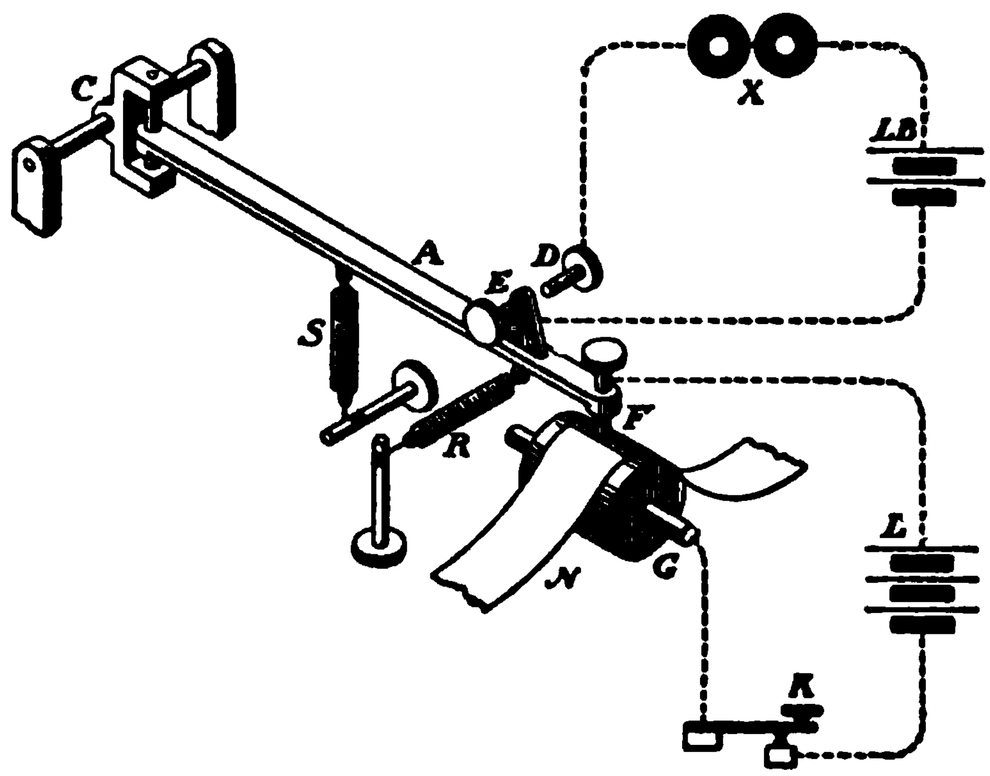


Fig. 83.—Edison's Electro-motograph. Note the means by which the slipping of the contact F is ensured.

Suppose now the key K is open, and that the friction of the platinum point F is sufficient to move the lever A, with the drum to the right, thus closing the circuit of LB. When, now, the key, K, closes the circuit, the current from the main battery, L, passes through the paper and produces an electrolysis of the chemical salt with which the paper is moistened. This decreases the friction and permits the spring, R, to draw the lever to the left, thus opening the circuit of the battery. Since the telegraphic sounder is included in the circuit of LB, these two movements of the telegraphic key, K, will have resulted in the movement of the striking lever of the telegraphic sounder.

Action of the electro-motograph

Edison has constructed a loud-speaking telephone on the principle of the electro-motograph. The general arrangement of this apparatus is shown in Fig. 84. Here the carbon transmitter, S, is placed in the circuit of the primary of an induction coil, I, and the battery B. The secondary of this coil has one terminal connected with the earth, E, and the

Edison's loud-speaking telephone.

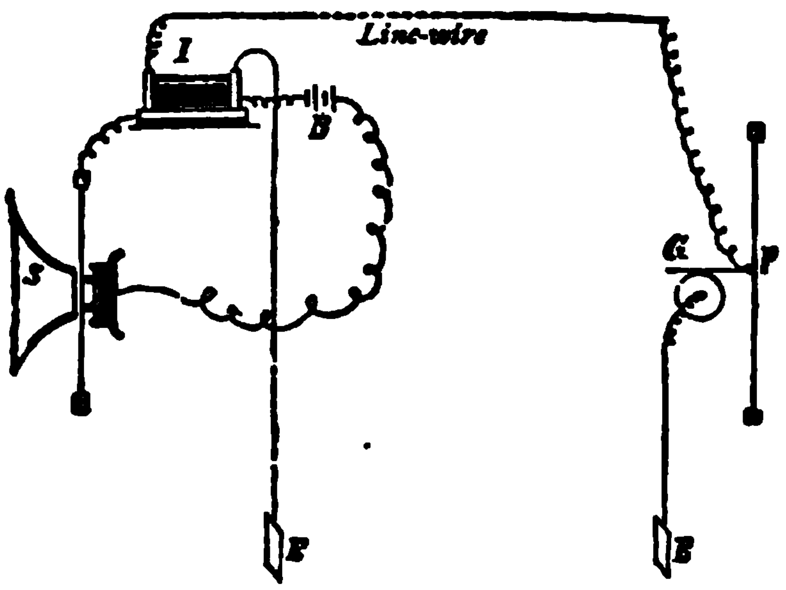


FIG. 84.—Edison's Loud-speaking Telephone.

other terminal connected with a spring, G, that is firmly attached to a mica plate, *p*. The cylinder on which the spring, G, rests is connected with the earth, E. A telephone so constructed reproduces sounds with great clearness and strength, so that they can be heard in different parts of a large assembly room.

CHAPTER XI

THE PHONOGRAPH, THE MICRO-PHONOGRAPH, AND THE PHOTOPHONE

"Science surpasses the old miracles of mythology."—EMERSON

Why a description of the phonograph is advisable in a book on telephonic appliances.

IT may seem curious that, in a portion of a book devoted to the electric telephone, we should find it necessary to give a description of the operation of the talking phonograph, an instrument that has nothing necessarily electric about it; and yet there are excellent reasons for so doing. In the first place, the manner in which the diaphragm of the talking phonograph repeats whatever has been spoken into the recording instrument is exactly similar, so far as the movements of the diaphragm are concerned, to that in the case of the receiver in the telephone. It is true, however, that it is quite different as regards the manner in which the record on the phonograph cylinder or metallic sheet imparts what has been impressed on it to the receiving diaphragm. The phonograph is an entirely mechanical appliance, while the telephone is either an electromagnetic or an electro-static appliance. But, in the second place, there have been some very curious combinations of telephonic and phonographic instruments, so that it is necessary to understand the phonograph in order to be able to understand any electric instrument in which the phonograph, or the principles involved in its operation, form an essential part.

The operation of the phonograph is exceedingly simple. A speaker talks against an elastic dia-

phragm of thin sheet iron or other metal, and causes it to move to-and-fro as in the telephone. Instead, however, of these to-and-fro movements expending their energy either in varying the electric resistance of the contact points in the microphonic transmitter, or of driving a small dynamo in the magneto-transmitter, they are caused to cut into or indent a surface of tin-foil or wax on a plate or cylinder.

The device employed by Edison in his early form of instrument is shown in Fig. 85, where a mouthpiece, M, is seen mounted on a stand directly in front of a metallic cylinder, C, in such a position that a **Edison's early form of phonograph.**

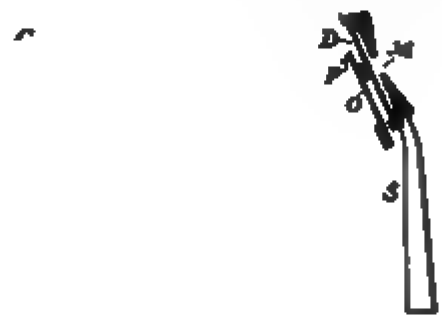


Fig. 85.—Edison's Phonograph. This is the early form of this valuable instrument.

metallic point, firmly attached to the centre of the diaphragm, presses against the surface of the tinfoil or wax. If now, while a person is speaking into the mouthpiece, the cylinder is slowly rotated by the movement of a crank at W, as the diaphragm moves to-and-fro under the influence of the sound waves, a metallic point connected with it will indent the surface of the cylinder, thus drawing a long, sinuous line, on which the to-and-fro movements of the diaphragm are correctly repeated by hills and hollows produced as the cutting tool makes indentations of varying depth, corresponding to the extent of the to-and-fro movements of the diaphragm.

How the phonograph record reproduces speech.

In order to cause the phonograph record so obtained to reproduce the speech or other sounds that have been impressed on the transmitting diaphragm, the phonograph record is placed on the surface of another cylinder precisely similar to that on which it was produced, or it may be kept on the same surface, and the tracing-point brought back to the position it had when it started to indent the surface of the record. If now this point be placed in the sinuous line, and pressed against it with proper force, as the cylinder is rotated, the point will be caused to pass over the record line, and to follow all the indentations that have been produced in it. As it is thus moved up and down the hills and hollows of the record surface, the diaphragm to which it is attached will be caused to move to-and-fro in movements that are similar to those which impressed the record. Consequently, the diaphragm will reproduce all the sounds that were originally spoken into it. In other words, the diaphragm will reproduce all the sounds and words that made the record.

Why the phonograph diaphragm reproduces speech.

By means of this remarkable instrument, a permanent record may be obtained of the voice of any person, and preserved for an indefinite period of time, being reproduced as often as may be desired. In a properly constructed and operated instrument, the quality of the voice, or the property which enables us to distinguish one voice from another, may be reproduced with sufficient distinctness to enable voices of different people to be readily recognized.

Resurrected voices.

When the phonograph was first invented, it quite naturally produced considerable astonishment, and a great future was confidently predicted for it. Assuming the possibility of obtaining an exact reproduction of the quality of the voice, of producing indestructible records, and of employing a standard

pitch for the screw of the phonograph cylinder, and a uniform speed at which it should always be rotated, it was predicted that correspondence would, in the then near future, be carried on by means of phonographic records, that wills would be made in which the intentions of the deceased would be declared to the assembled heirs, not by a paper read by a lawyer, but in the reproduced spoken words of the deceased. It was predicted that there would be galleries in which pictures or statues of the world's departed great would be replaced by phonograph records; that great writers might be made actually to convey their thoughts by the spoken words instead of by the printed page; that the speeches of the world's great orators and the sweet strains of its greatest singers would be reproduced at will at any time in the future. Some of these predictions have been fulfilled, and some have not. It is not true that the phonograph can so successfully reproduce the human voice as to enable it to be recognized beyond doubt, since the very fact that the metallic point connected with the reproducing diaphragm is obliged to move in frictional contact with the record, introduces in all cases sounds that are absent in the human voice. Moreover, a difficulty is experienced in correctly reproducing those overtones, the presence of which is necessary in order to obtain the exact quality of the voice. For this and for other reasons some of the predictions before referred to have failed of realization.

Optimistic predictions of phonograph's great future.

Edison has greatly improved his phonograph. In the first place, he has substituted a cylinder of hardened wax for the sheet of tin-foil, and, in order to ensure a greater regularity in the rate of motion of the cylinder, he has added an electric motor for driving it. The improved form of instrument is

Edison's improved phonograph.

shown in Fig. 86. Here the recording diaphragm is made of malleable glass. A mouthpiece is attached to a flexible tube connected with the diaphragm, for convenience in speaking or singing in recording the voice. The recording diaphragm is distinct from the receiving diaphragm. Either can replace the other by the simple rotation of a metallic arm on which both diaphragms are supported.

FIG. 86.—Edison's Improved Phonograph. Compare the details of this instrument with that represented in Fig. 85.

Poulson's great invention.

Various devices have been proposed for increasing the delicacy of the phonographic records, so as to enable them more nearly to reproduce the quality of the human voice. One of the most remarkable of these improvements is embodied in an instrument invented by a Danish electrical engineer, Waldemar Poulson, of Copenhagen. Here both the making of the record and the reproduction of the speech by the record are obtained by means of electricity and magnetism, so that, in point of fact, the phonograph is now replaced by a telephone transmitter and a dynamo-electric generator, in a manner that we will now describe.

Various names have been given to Poulson's instrument. It has been styled the tele-phonograph, the micro-phonograph, the magneto-phonograph, and the tele-graphophone. The general name ap-

The micro-phonograph.

Fig. 87.—Poulson's Steel Wire Micro-phonograph.

plied to it in this country is the micro-phonograph. The record material consists of a length of hardened steel piano wire, about $\frac{1}{25}$ of an inch in diameter. This wire is wound on the surface of a cylinder about a foot in length, arranged as shown in Fig. 87. A tiny electro-magnet is placed so that

A B C D

Fig. 88.—Magnets for Poulson's Micro-phonograph.

its opposite poles embrace the wire in the manner shown at B, Fig. 88. As this drum or cylinder is revolved by the action of an electric motor, the magnet is caused to move over the entire length of the

How the record is moved in the micro-phonograph.

wire, from right to left, and so to travel from one end of the cylinder to the other. In this manner the magnet poles pass above the entire length of the wire wound on the drum, this length consisting of about 225 turns of wire, the magnet requiring about thirty-nine seconds to move over the entire length of the wire.

How the micro-phonograph record is impressed on the steel micro-phonograph wire.

So much for the movement of the record wire. Now let us investigate the manner in which the voice, as in speaking or singing, is enabled to impress its record on the wire. The insulated coils of wire on the recording electro-magnet are placed in the circuit of an ordinary carbon telephone transmitter and a couple of cells of a voltaic battery. Generally an induction coil is employed in the transmitting instrument in the usual manner, in which case its secondary is connected with the coils of the recording magnet, while a carbon transmitter is included in the circuit of a small battery and the primary of the induction coil. On speaking into the transmitter, variations in the resistance of the carbon contact points produce corresponding variations in the current strength passing, and these variations, passing through the coils of the electro-magnet, magnetize the steel wire as it passes between the magnet poles. Of course this magnetization of the steel wire takes place transversely to the axis of the wire. There will thus be left in the steel wire an invisible but permanent record of the variations in the magnetic intensity that have been impressed on the record magnets by the influence of the sound waves on the transmitting diaphragm.

The record being made, let us see how it is caused to reproduce the sound by means of the invisible records left by the recording magnets. Placing the

record magnet at the beginning of the record on the wire, and placing its coils in the circuit of an ordinary Bell receiving telephone, the cylinder is again caused to revolve by the action of the electric motor. The magnetized steel wire, taken in connection with the coils of wire on the poles of the electro-magnet, constitute a dynamo-electric generator, and as the magnetized steel wire is passed between these poles it will cause magnetic flux to alternately fill and empty the coils of wire on the magnet with magnetic flux, thus producing E.M.F.'s, and, consequently, currents that will correspond exactly in strength, direction and sequence to the current that, passing through the magnetizing poles of the recording magnet, left their impress on the record wire. These currents, passing through the coils of wire on the Bell receiving telephone, will, therefore, produce movements in its diaphragm which will reproduce all the speech or musical notes originally uttered and impressed on the transmitting diaphragm.

How the magnetized steel record wire is caused to reproduce the sounds recorded.

It has been found in practice that, in order to permit the electro-magnets to respond with sufficient rapidity to variations produced in the transmitter by the sound waves, it is necessary to employ two separate electro-magnets electrically connected, as shown at C, in Fig. 88. An electro-magnet, wound in the regular manner, as shown at B, in the same figure, has been found to be too slow in its action to ensure the best results. This beautiful apparatus performs its work in an exceedingly efficient manner. The quality of the spoken voice is reproduced with a clearness that is unknown in the phonograph; for the scratching sounds before referred to are avoided, and the micro-phonographic record is able to produce overtones in a manner far superior to that of the phonograph. Moreover, this instrument

The micro-phonograph far more sensitive than the phonograph.

is far more sensitive than the phonograph, since it will readily record sounds of all characters, even, for example, such as breathing and whispering, which, as is well known, are very difficult to properly record in the ordinary phonograph.

Improved form of micro-phonograph.

An improved form of micro-phonograph is represented in Fig. 89, where two separate reels are employed, on which a band of steel ribbon, $\frac{3}{16}$ of an inch wide and about $\frac{1}{16}$ of an inch thick, is employed.

FIG. 89.—Band Micro-phonograph.

The ribbon can readily be made in any desired length, so as to enable it to record continuously spoken language for an hour or longer. It has been found for recording on ribbon that the form of electro-magnet shown at D, in the preceding figure, is preferable. As regards the permanency of the records, it is claimed that the record wires or ribbons can be wound on a spool, with the layers of the ribbon one over the other, without injury, and that such a record ribbon has been used for 2,200 times without exhibiting any signs of dete-

rioration. When it is desired to obliterate the record, it is only necessary to transmit a constant magnetizing current through the coils of the recording magnet, and move the steel wire or ribbon underneath such magnet. The same can be done by the action of a permanent magnet. Obliteration of records.

As to the future possibilities of this wonderful instrument, it is easy to see that these are many and great. One suggestion—indeed, it has gone further than a mere suggestion, having been carried into

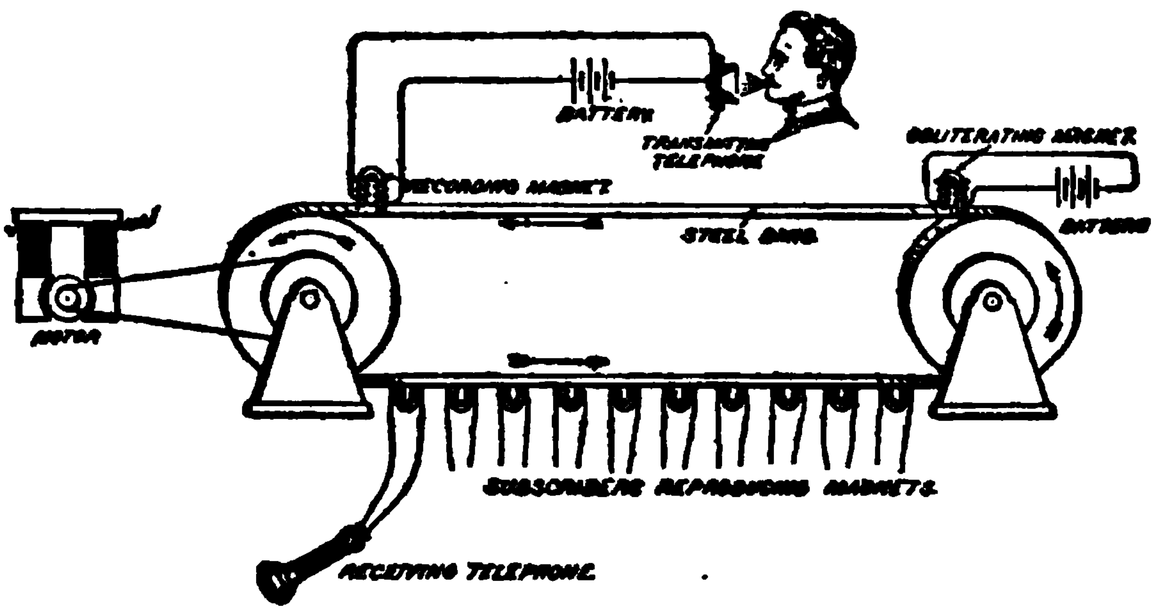


FIG. 90.—The Talking Newspaper. Note the arrangements to ensure the proper working of this application of the micro-phonograph.

actual practice in Europe—is a device that we fear may tend to a marked increase in the slothfulness of the rising generation. We refer to the plan of the talking newspaper, that is, a newspaper which is capable of reading itself, and only requiring the attention of the person to what it says, so that it would be possible for one to lie in bed, with the receiving instrument at his ear, and listen to the news whenever he might desire to do so. In this very ingenious invention an endless steel ribbon is employed, whose record ribbon consists of a steel band, that passes from one reel to another in the direction indicated by the arrows, Fig. 90. Recording tele- The talking newspaper.

phones are attached to a number of magnets placed so that the record ribbon passes before their poles. After the ribbon has passed these magnets, it may, if so desired, have all its records obliterated by an obliterating magnet, while, at the same time, additional news concerning prices of stock, war, and items of interest generally, are recorded afresh on the moving band through the transmitting telephone represented in the figure.

Bell and Tainter's photophone

But there is a still more wonderful instrument, whose operation depends generally on the principles of the telephone, that is yet to be described. This is the photophone, an apparatus by means of which it is possible to talk along a ray of light. Instead of stretching a conducting wire between the transmitting and the receiving stations, it is only necessary to flash a beam of light between them, and so influence this beam, by means of a transmitting instrument at one end, as to cause it to affect the receiving instrument at the other end. This invention was made by Bell and Tainter. It depends for its operation on the fact we have already referred to, that, under certain circumstances, the electric resistance of selenium is considerably changed by the action of light falling on its surface.

Action of photophone transmitter.

The transmitting instrument of the photophone consists of a suitably supported thin plate of silvered glass or mica, L, Fig. 91, which acts as a mirror or reflector, and is suitably supported and provided with a mouthpiece, E. A beam of light from any powerful source, such, for example, as an arc light, or still better, light from the sun, is allowed to fall on the reflecting diaphragm, being concentrated on its surface by a lens, A. The rays of light, after their reflection from the mirror at L, are

again made parallel by a passage through a second lens, B. On speaking into the transmitting diaphragm at A, the mirror is moved rapidly to-and-fro, a change of shape being produced by these movements, so that there will be thereby occasioned a scattering of the rays of light, which results in the amount of light that is reflected from the mirror being rapidly varied in accordance with the sound waves that strike the transmitting diaphragm.

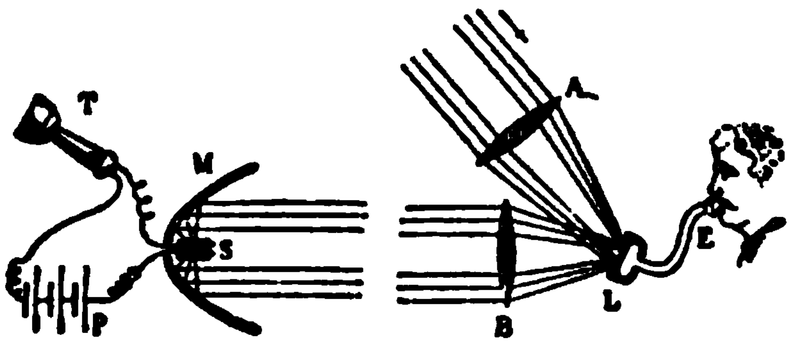


FIG. 91.—Bell and Tainter's Photophone. Note how the person speaking at E modifies the rays of light and the manner in which these rays are afterward caused to fall on the selenium cell at S.

Construction and operation of photophone receiver.

Coming now to the receiving station, we find here a parabolic mirror, M, which receives the parallel rays of varying intensity, and reflects them on to the surface of a selenium cell, S, whose terminals are included in the circuit of the receiving telephone, T, and the voltaic battery, P. This selenium cell consists practically of an extended surface of selenium, placed between two parallel metallic plates. In order to concentrate the selenium cell in a small space, a series of brass disks, separated by disks of mica, of somewhat smaller diameter than the brass disks, is employed, the whole taking the shape of a pile, as shown at S, in the figure, so that the surface of the cylinder has the appearance of being deeply grooved. The brass disks are connected alternately in two series, like the opposite coatings of a Leyden jar, and melted selenium is poured in between the brass plates. When a beam of light falls on such a selenium cell, it causes its resistance to

Construction of selenium cell.

greatly vary. Consequently, the varying rays of light coming from L fall on the surface of S, so that the resistance of the receiving telephone varies in accordance with the sound waves impinging on the diaphragm at E. Such sounds will, therefore, be reproduced in the receiving diaphragm. The photophone has been successfully operated over comparatively short distances, and has been found to reproduce speech with great distinctness. A similar arrangement of the transmitting and receiving

Transmitter and receiver of photophone

Fig. 92.—Transmitter of Photophone. Note the direction of the rays of light as indicated by the arrows.

instruments is shown in Figs. 92 and 93, respectively. The operation, however, is practically the same as that already described.

Name of radiophone proposed for photophone.

In the photophone the transmission of speech and musical sounds is effected by means of a beam of light; hence, the propriety of the term photophone. The name radiophone has been proposed for these instruments by Mercadier, a Frenchman, by reason of the curious fact that was discovered by Tainter and others, that luminous rays are not necessary to

produce this transmission, but that non-luminous, or heat rays, are equally able to transmit speech. In some of his experiments, Tainter employed a resistance composed of a zigzag line of soot in the place of the selenium cell. This arrangement is called a carbon or soot cell, and is shown in Fig. 94.

Tainter's carbon or soot cell.

FIG. 93.—Receiver of Photophone. Note the connection of the receiving telephones with the selenium cell and battery P.

Here a silvered glass plate, P, has its silvered surface removed in the form of a zigzag line, Z, Z. This line is covered with soot or lampblack, so that the sinuous line divides the surface of the glass into two parts, that are connected by means of separate clamps, K, K, with the battery and the receiving telephone. When rays of either heat or light are reflected from the surface of a transmitting dia-

phragm similar to that shown at L, Fig. 91, and fall on the surface of the soot cell, variations in its resistance are produced, and, consequently, speech or musical sounds are heard in the receiving telephone.

FIG. 94.—Carbon or Soot Cell for Photophone. The long sinuous or zigzag line of soot is represented at Z, Z.

It was soon discovered, however, that the mass of carbon or soot, when under the influence of the rapidly intermitting beams of heat or light falling

on it, emitted distinct sounds, so that it was not necessary to employ a battery and a telephone. If the mass of air surrounding the soot cell is confined in a hollow space provided with a diaphragm, all that is spoken into the transmitter can be distinctly heard without the use of either the battery or the receiving telephone. The property possessed by certain solid substances of thus emitting sounds when intermittent rays of light or heat fall on their surfaces, has been named sonorescence. Hard rubber or vulcanite has been found to possess the property of sonorescence in a high degree.

Sonorescence.

III

ELECTRIC TELEGRAPHY

CHAPTER XII

EARLY HISTORY OF TELEGRAPHY

"He said to his friend, 'If the British march
By land or sea from the town to-night,
Hang a lantern aloft in the belfry arch
Of the North Church tower, as a signal light,
One, if by land; two, if by sea.'"

—Longfellow

WE have no positive knowledge as to just when and how telegraphy began. Taking the strict etymological meaning of the word—*i.e.,* writing at a distance, or communicating intelligence by means of audible or visible signs—the first system of telegraphic communication was, probably, practiced by some of our remote savage ancestors, who warned one another of coming danger by various calls, that were able to penetrate to far greater distances through the dense forests than could any visible signals. Indeed, even to the present day, it is stated that the African negroes on the west coasts of the continent employ such signalling devices, having provided for themselves an instrument called the "Elliembic," a rude musical instrument, which, on striking, produces sounds which enable the natives to carry on conversations with one another, though several miles apart. This instrument, when properly used, is able to produce sounds that form an intelligible language. But even if we knew the first of the human race who employed

Possible forerunner of the electric telegraph.

The Elliembic.

such means of telegraphic communication, we could not claim for him entire originality, since such methods have long been in use by birds and other animals. Ernest Seton-Thompson, the lover of animals, has even gone so far as to write out in musical notation the various calls of crows as they signal to one another matters of coming danger or of common interest. Possibly, after such systems of audible telegraphy, various systems of visual telegraphy were invented, such as were seen in the light of the beacon fire, whereby intelligence of various kinds was flashed across the country from one place to another. Audible telegraphy, for example, has been practiced, both with the fog-horn on the ocean steamer and the whistle of the locomotive, during foggy weather, by employing audible signals corresponding in duration and sequence to the telegraphic characters of the Morse alphabet. Even before this, various fog-horn systems had been employed on all vessels. Visual signals, too, have been even more fully developed in what are generally known as various systems of semaphoric signalling. Such signals consist generally in signalling by means of visual signs, such as flags, or other recognizable movable objects by day, or lanterns by night.

Calls of the crows.

Audible telegraphy.

Semaphoric signalling.

One of the first completed systems of semaphoric telegraphy dates back as far as 1684; viz., that of Locke, who devised a system of wooden blocks of various shapes, sufficiently large to be seen at a distance. By arranging these blocks in various ways to indicate the letters of the alphabet, he was enabled to communicate, between distant stations, intelligence of various characters, by spelling out the information which it was desired to transmit.

Locke's semaphoric signals.

It was just one hundred years later, when a

Frenchman, by the name of Claude Chappé, was a student at the College of Angiers, France. Chappé, who was forbidden by the strict rules of the school to communicate freely with his brother in a neighboring college—which, although situated at some distance, yet was visible—devised, in connection with his brother, a system of semaphoric signalling, by which, through the movements of a pivoted arm, they were able to indicate various letters of the alphabet by pointing the arm in different directions. Subsequently, they increased the number of these visual signals by the addition of small movable beams, attached to the end of the main beam. At the end of their college life they had devised some 192 distinct and separate signals. Apparatus thus begun, as a means of recreation to while away the tedious hours of school life, was, after the completion of their college life, adopted by the French Government, and constituted the beginning of a system of semaphoric signalling that, before the introduction of the simpler method of electro-magnetic signalling, extended over a large part of the civilized world. One of the Chappé brothers afterward became the chief telegraphic engineer for the French Government, and the semaphoric system of telegraphic communication was rapidly extended along a greater part of the French coasts.

Origin of Chappe's semaphoric signalling system.

Adopted by Fthe rench Govern-ment.

The Chappé semaphoric telegraph was improved by an Englishman named Murray, in 1795, and was adopted by the English Government in 1816. Continued improvements were made in the semaphoric telegraph until 1832, when the distinct signals capable of being thus transmitted had reached the number of 4,096. The system of semaphoric communication was adopted by the Prussian Govern-

THE LANDING OF A SUBMARINE CABLE

ment in 1832, and was subsequently employed in the Empire of Russia. Here remains of the expensive signal towers can still be seen along the lines of the government electric telegraph, which has replaced the semaphoric system.

The thoughts of ingenious men from very early times have been directed to devising systems whereby early information shall be obtained of passing events. Consequently, we find in early literature various suggestions as to how intelligence might be readily communicated between distant points. One of these, made by Strada, dates back as far as 1615, and is thus described in an old book:

Desire for early information of passing events.

"Strada's fancy was this. There is, he supposes, a species of lodestone which possesses such virtue that if two needles be touched with it, and then balanced on separate pivots, and the one be turned in a particular direction, the other will sympathetically move parallel to it. He then directs each of these needles to be poised and mounted on a dial having the letters of the alphabet arranged round it. Accordingly, if one person has one of the dials, and another the other, by a little prearrangement as to details, a correspondence can be maintained between them at any distance by simply pointing the needles to the letters of the required words."

Strada's fancy.

As soon as it was discovered that an electric discharge could be rapidly transmitted through conducting bodies, efforts were made to employ electricity for the communication of intelligence. Various systems of electric telegraphs were suggested. The first of these were operated by electric discharges, and afterward by electro-magnetism. It will be interesting to rapidly review some of the more important of these early efforts in electric telegraphy.

Gray's electric telegraph.

In 1727, Stephen Gray, to whom we have already referred in connection with frictional electricity, succeeded in passing an electric discharge through a wire some 700 feet in length, suspended in the air by means of silk threads. In operating this first electric telegraph, Gray held an excited glass tube to one end of the line, when an observer at the other end noted its effect in attracting a pith-ball electroscope.

Watson's electric telegraph.

In 1747, Dr. Watson, Bishop of Landaff, employed the discharge from a Leyden jar for producing electric effects at the end of a suitably insulated metallic conductor. In some experiments, he succeeded in passing the discharge of a Leyden jar through a circuit four miles in length, and called attention to the fact that the discharge required no appreciable time to pass over this distance. During the same year, Watson erected a telegraph line that extended from the rooms of the Royal Society in London, over the chimney tops. This line was formed of a single wire, the ground being employed for the return circuit. As in Watson's former experiments, the charge of a Leyden jar was employed for operating the signals.

Franklin ignites alcohol by electric circuit across the Schuylkill.

In 1748, Franklin stretched a metallic wire across the Schuylkill River at Philadelphia, employing the earth for the return circuit. By means of this wire, he succeeded in igniting some alcohol in a plate by the discharge of a Leyden jar on the opposite side of the river.

C. M's remarkable letter in 1753.

While it is true that none of these experiments can be regarded as anything more than mere suggestions, yet they soon bore fruit. Intelligent men in different parts of the world were not backward

in proposing plans by means of which communication might be established by electric discharges. Of these suggestions, however, we will mention but one; viz., that made to the Editor of "Scott's Magazine," in 1753, by a correspondent who signed himself C. M.:

"RENFREW, *Feb.* 1, 1753.

"SIR—It is well known to all who are conversant in electrical experiments, that the electric power may be propagated along a small wire, from one place to another, without being sensibly abated by the length of its progress. Let, then, a set of wires, equal in number to the letters of the alphabet, be extended horizontally between two given places, parallel to one another, and each of them about an inch distant from that next to it. At every twenty yards' end, let them be fixed in glass, or jeweller's cement, to some firm body, both to prevent them from touching the earth or any other non-electric, and from breaking by their own gravity. Let the electric gun-barrel be placed at right angles with the extremities of the wires, and about one inch below them. Also, let the wires be fixed in a solid piece of glass, at six inches from the end; and let that part of them which reaches from the glass to the machine have sufficient spring and stiffness to recover its situation after having been brought in contact with the barrel. Close by the supporting glass, let a ball be suspended from every wire; and about a sixth or an eighth of an inch below the balls place the letters of the alphabet, marked on bits of paper, or any other substance that may be light enough to rise to the electrified ball; and at the same time let it be so continued that each of them may reassume its proper place when dropped. All things constructed as above, and the minute previously fixed, I begin the conversation with my distant

Proposes a telegraphic line.

Transmitting and receiving apparatus.

Describes method of transmitting a message.

friend in this manner: Having set the electrical machine a-going as in ordinary experiments, suppose I am to pronounce the word *Sir:* with a piece of glass, or any other *electric per se,* I strike the wire *s,* so as to bring it in contact with the barrel, then *i,* then *r,* all in the same way: and my correspondent, almost in the same instant, observes these several characters rise in order to the electrified balls at his end of the wires. Thus I spell away as long as I think fit; and my correspondent, for the sake of memory, writes the characters as they rise, and may join and read them afterward as often as he inclines. Upon a signal, given, or from choice, I stop the machine; and taking up the pen in my turn, I write down whatever my friend at the other end strikes out.

Describes a receiver consisting of a chime of bells.

"If anybody should think this way tiresome, let him, instead of the balls, suspend a range of bells from the roof, equal in number to the letters of the alphabet, gradually decreasing in size from the bell A to Z; and from the horizontal wires let there be another set reaching to the several bells; one, viz., from the horizontal wire A to the bell A, another from the horizontal wire B to the bell B, etc. Then let him who begins the discourse bring the wires in contact with the barrel, as before; and the electric spark, breaking on bells of different size, will inform his correspondent by the sound what wires have been touched: and thus, by some practice, they may come to understand the language of the chimes in whole words, without being put to the trouble of noting down every letter.

"The same thing may be otherwise effected. Let the balls be suspended over the characters as before, but instead of bringing the ends of the horizontal wires in contact with the barrel, let a second set reach from the electrified cable, so as to be in con-

tact with the horizontal ones; and let it be so contrived at the same time, that any of them may be removed from its corresponding horizontal by the slightest touch, and may bring itself again into contact when set at liberty. This may be done by the help of a small spring and slider, or twenty other methods, which the least ingenuity will discover. In this way, the characters will always adhere to the balls, excepting when any one of the secondaries is removed from contact with its horizontal; and then the letter at the other end of the horizontal will immediately drop from its ball. But I mention this only by way of variety.

"Some may, perhaps, think that, although the electric fire has not been observed to diminish sensibly in its progress through any length of wire that has been tried hitherto, yet, as that has never exceeded some thirty or forty yards, it may be reasonably supposed that in a far greater length it would be remarkably diminished, and probably would be entirely drained off in a few miles by the surrounding air. To prevent the objection, and save longer argument, lay over the wires from one end to the other with a thin coat of jeweller's cement. This may be done for a trifle of additional expense; and as it is an *electric per se,* will effectually secure any part of the fire from mixing with the atmosphere.

Proposes to insulate the line wires.

"I am, etc., C. M."

The first actual working telegraphic line was established in 1774, at Geneva, by a Frenchman named Lesage. Here some twenty-four conducting wires, insulated by glass tubes buried in the earth, were employed. An ordinary frictional machine was used for exciting the separate wires.

Lesage's electric telegraph.

Any system of telegraphic communication by means of pith balls, such as that above described

by Lesage, would of course be open to the objection that some little time would be necessary for the pith balls to lose their charge. It is for this reason that Lesage suspended the pith balls he employed in his system on cotton and linen threads instead of on silk threads. He also probably discharged his line after the transmission of each letter or numeral.

Lomond's semaphoric electroscope.

In 1787, Lomond greatly improved Lesage's system of telegraphic communication by employing only a single wire between stations, and using a single delicate electroscope at each end of the line. This he accomplished by the ingenious idea of causing the movable part of the electroscope to act as a species of semaphoric signal, the various positions occupied by the movable part representing the various letters of the alphabet, and the numerals. The following description of this instrument is that given in a book by Young, called "Travels in France," published in 1787:

Description of Lomond's apparatus.

"M. Lomond has made a remarkable discovery in electricity. You write two or three words on a paper; he takes it into a room, and turns a machine enclosed in a cylindrical case, at the top of which is an electrometer, a small fine pith ball; a wire connects with a similar cylinder and electrometer in a distant apartment; and his wife, by remarking the corresponding motions of the ball, writes down the words they indicate, from which it appears that he has formed an alphabet of motions. As the length of the wire makes no difference in the effect, a correspondence might be carried on at any distance, within or without a besieged town, for instance, or for objects more worthy of attention and a thousand times more harmless."

Betancourt, 1787.

In 1787, Betancourt, in Spain, endeavored to employ electricity for telegraphing through a line wire

some 26 miles in length between Madrid and Aranjuez. Leyden-jar discharges were employed.

In 1796, De Salva, another Spanish philosopher, described before the Academy of Madrid a form of telegraphic apparatus which he had invented. The following description of this instrument appeared in the "Gazette de Madrid" on November 25, 1796: De Salva, 1796.

"The Prince de la Paix having learnt that M. de F. Salva had read at the Academy of Sciences a memoir on the application of Electricity to telegraphic purposes, and presented at the same time an electric telegraph of his own invention, wished to examine it; and charmed with its promptitude and the facility of its operations, he showed it afterward to the King and to the court, when it performed equally well. After this experiment, the Don Antonio wished to obtain a more perfect telegraph, and undertook a calculation of the force of the Electricity required to work a telegraph at different distances under land and water." De Salva's electric telegraph.

In 1795, Cavallo, to whom reference has already been made, proposed an ingenious system of telegraphy, in which the letters of the alphabet, and the numerals, were represented by various combinations of sparks and intervals between the sparks, observed at one end of a line and produced by means of timed impulses sent over the line from the other end. Cavallo, 1795.

All the early experiments in telegraphy to which we have referred were made before the invention of the voltaic battery. As we can readily understand, none of them was commercially successful. Not that they might have been carried into actual practice, but for the difficulties which would necessarily Why early telegraphic systems were commercially inoperative

arise in those early days from the absence of properly insulated lines, as well as those which would result from the difficulty of readily obtaining the suitable electric discharges under varying conditions of the atmosphere, naturally prevented any of them from coming into extended use. As soon as the invention of the voltaic battery placed in the hands of scientific men a reliable electric source, methods of telegraphic communication were proposed, and actual systems were produced, capable of ensuring far more practicable methods of telegraphic communication than any that had previously been proposed. One of the first of these, indeed one of the first actual working lines ever produced, was that devised by Prof. Soemering, of Munich, in 1812. This, as will be noticed, was not very long after the invention of the voltaic cell. Soemering's electric telegraph was based on the discovery made by Nicholson and Carlisle, of the power possessed by the current of a voltaic battery to decompose water. It was the first electro-chemical telegraph, all subsequent instruments of this class being practically based on similar principles. Soemering's instrument is thus described by the inventor:

Soemering's electro-chemical telegraph.

"My telegraph was constructed and used in the following manner: In the bottom of a glass reservoir containing acidulated water, AA, Fig. 409 [our Fig. 95], are 35 golden points or pins passing up through the bottom of the glass; each pin corresponds to one of the letters of the alphabet and to the ten numerals. The 35 points are each connected with an insulated copper wire soldered to them, and extending to the distant station BB, where they are soldered to 35 brass plates fixed transversely on a wooden bar; through the front of each of the plates there is a small hole for the reception of two brass pins, one of which is connected

Soemering's description of his electro-chemical telegraph.

with the positive and the other with the negative pole of a voltaic pile, CC. Each of the 35 plates is arranged to correspond with the arrangement of the 35 gold points in the glass reservoir, and are lettered accordingly. When thus arranged, the two pins from the column are held one in each hand; and the two plates being selected, the pins are then put into their holes and the communication is established; gas is evolved at the two distant corresponding points in an instant; the peg on the hydrogen pole evolves hydrogen gas; and that on the oxygen

FIG. 95.—Soemering's Electro-chemical Telegraph. Contrast this early form of telegraph, with its many separate circuits, with the simple Morse apparatus of to-day.

pole, oxygen gas. In this way every letter and numeral may be indicated at the pleasure of the operator."

Line wires employed by Soemering's electro-chemical telegraph.

Another representation of the Soemering telegraph, in which some of the details are more clearly seen, will be found in Fig. 96. Here the keys representing the different letters of the alphabet and the numerals are shown at A, B, C, D—1, 2, 3, etc., with the circuit connections extending to the distant station, where they terminate in the voltameters represented at A, B, C—1, 2, 3, etc. Soemering employed 35 separate line wires, 25 for the letters of the German alphabet and 10 for the numerals. He employed a mechanical signal or call-bell, which

was thrown into action by means of gases that accumulated in a bell jar, when liberated by means of a current sent over the line.

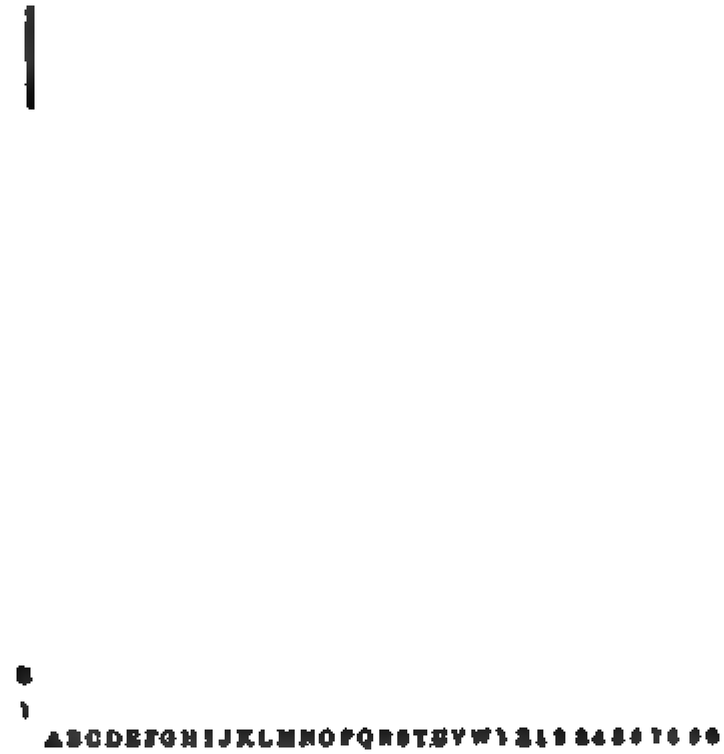


Fig. 96.—Soemering's Electro-chemical Telegraph.

Coxe's electro-chemical telegraph.

About the same time that Soemering announced his invention of the electro-chemical telegraph, Dr. Coxe, of Philadelphia, without any knowledge of Soemering's invention, described a similar method for transmitting intelligence. Here signals were received at the distant end of the line either by the decomposition of water, or a metallic salt.

Influence of Oersted's discovery on telegraphy

Oersted's discovery of the production of magnetism by electricity marks a great era in the history of the telegraph. None of the many effects that an electric discharge or current is capable of producing lends itself so readily to the transmission of telegraphic signals as do the attractions and repulsions produced by electro-magnets. The scientific world recognized this fact, and various propositions to employ this new agency were made

almost immediately after its announcement. Oersted was first in the field, with a proposal to employ his discovery for the operation of an electric telegraph. He was almost immediately followed by Ampère, who, in a memoir presented to the Royal Academy of Sciences in Paris, on the 2d of October, 1820, disclosed a plan for an electric telegraph, the operation of which depended on the deflections of a magnetic needle surrounded by coils of wire, through which the currents were passed. Neither Oersted's nor Ampère's suggestions appear ever to have been put into practice. Ampère thus speaks of this instrument:

Suggestions of Oersted and Ampère for electro-magnetic telegraphs.

"The success of this experiment demonstrates that by employing as many conducting wires and magnetic needles as there are letters, and by placing each letter under a different needle, signals may be communciated by a pile placed at a long distance off. The communication between the pile and the different coils was to be opened and shut by means of a set of keys."

Ampère's electro-magnetic telegraph.

Passing by a number of suggestions and actually constructed apparatus, we come to the great invention of the electro-magnet by Sturgeon, in 1825, and its subsequent marked improvement by Henry, already referred to. This invention marked another era in the history of the telegraph, even greater than that of Oersted's discovery, since practically all the telegraphic apparatus of to-day is based on the operation of electro-magnets. Sturgeon gave his first electro-magnet the form represented in Fig. 97, where a core of soft iron, bent in the well-known form of the horseshoe, is surrounded by magnetizing coils of insulated wire. Sturgeon wound these coils in the same direction around the entire core, so that the ends or poles were of north and south

Sturgeon and Henry.

polarity respectively. An armature of soft iron was placed before the poles. Henry, besides improving the construction of the electro-magnet by employing the insulated wire of many turns, pointed out the important fact that it was the number of voltaic cells, and not the size of the plates, that determined the strength of the electro-magnet.

CHAPTER XIII

MORSE AND HIS CONTEMPORARIES

"I'll put a girdle round the earth
In forty minutes."
—*A Midsummer-Night's Dream*, Act II, Scene I

IT is seldom that an apparatus comes from the brain of an inventor so complete in its details that it is capable of working on a commercial scale. In nearly all cases it needs the aid of many separate inventors to supply working details. This has been essentially the case in the history of the electric telegraph. We have already alluded to many of the able scientific men who took their part in this great invention. We have shown that without Volta's invention of the battery the telegraph could not have been commercially possible; that without the discovery of Oersted it never could have commenced to assume its present condition; without the efficient electro-magnets produced by Sturgeon and Henry it never could have started on its great era of use. But we have still an additional discovery to record, without which the present high development of the electro-magnetic telegraph would have been utterly impossible. We allude to the production by Daniell of the constant voltaic battery, in 1836. Before the time of this invention, the tendency of all voltaic batteries to polarize, and thus rapidly decrease in the strength of the current they produced, was so marked that even if satisfactory systems of telegraphy had been devised, it would have been almost impossible to employ them continually on a

Combined work of many scientific men necessary for the production of the electro-magnetic telegraph.

Influence of invention of Daniell's voltaic battery.

commercial scale. Telegraphic apparatus require very delicate adjustments, and if the current strength was constantly varying, these adjustments would have been practically impossible.

1837 a year memorable in telegraphy.

Inventors were not slow in availing themselves of the possibilities of the Daniell constant cell. 1837 was a year memorable in the history of electric telegraphy. Almost simultaneously three notable inventions were made; viz., by Morse in the United States, by Steinheil in Munich, and by Wheatstone and Cooke in England. Of these inventors, Morse, in America, was the first to conceive of his invention, carrying it back, as he did, as far as 1832. It does not appear, however, that he actually built his working apparatus before 1837. Morse's invention was singularly complete, considering the early date at which it was made, and was in such a state when he produced his first working model that it was practically the same as the system of electromagnetic telegraphy that is to-day generally employed in the United States, as well as in many other parts of the world.

Morse, Steinheil, Wheatstone and Cooke.

Morse made his great invention of the recording telegraph when forty-one years of age, during a voyage across the Atlantic Ocean. He made sketches of his invention at this time, which, however, were not embodied in actual working apparatus until a later date. Morse himself in after years refers to these early notes as follows:

Morse proposes to employ mechanical and chemical markings for records

"Before the end of the voyage on the 'Sully' the invention had the following attributes. My aim at the outset was simplicity of means, as well as results. Hence, I devised a single circuit of conductors from some generator of electricity. I planned a system of signs, consisting of dots or points, and

spaces, to represent numerals, and two modes of causing the electricity to mark or imprint these signs upon a strip or ribbon of paper. One was by chemical decomposition of a salt which should discolor the paper; the other was by the mechanical action of the electro-magnet, operating upon the paper by a lever, charged at one extremity with a pen or pencil. I conceived the plan of moving the paper ribbon at a regular rate, by means of clock-work machinery to receive the signs. These processes, as well as the mathematically calculated signs, devised for and adapted to recording, were sketched in my sketch-book. I also drew in my sketch-book modes of interring the conductors in tubes in the earth, and, soon after landing, planned and drew out the method upon posts. This was the general condition of the invention (with the exception of the plan upon posts) when I arrived in New York, on the 15th of November, 1832.

Morse suggests underground wires.

"In reflecting on the operations of electricity as a proposed agent in telegraphy, I was aware that its presence in a conductor of moderate length could be indicated in several ways. The physical effects in a shock; the visible spark; visible bubbles during decomposition, and marks left from decomposition; its magnetic effects upon soft iron and steel; and its calorific effects—these were all well-known phenomena. Could any of these be made available for recording, and at a great distance? If so, which of them seemed to promise the surest result of a permanent record? Static electricity was quickly dismissed as too uncontrollable, and I directed my attention exclusively to the phenomena of dynamic electricity. The decomposition of a salt having a metallic basis would leave a mark upon paper or cloth. If a strip of paper or cloth were moistened with the salt, and were then simply put in contact

Morse's thoughts in regard to means for recording messages.

with a conductor charged with electricity, would there be any effect upon the paper? A magnetic effect is produced exterior to the charged conductor. Is there any salt or substance so sensitive as to be affected either by decomposition, or in any other way, by this magnetic influence, by simple contact with an electrically charged wire? It was doubtful, but worth an experiment."

The first electro-magnetic telegraph in America.

A variety of circumstances prevented Morse from constructing his first rude model until 1835. His electro-magnet was exceedingly crude. It was constructed of a bent rod of iron, on which a few yards of copper wire was placed, insulated by wrapping cotton thread around it by hand. The different parts of the apparatus were supported on a wooden frame, nailed to one side of a table, as shown in Fig. 97. Three wooden cylinders, A, B, and C, were placed as shown. A paper ribbon, wound on the cylinder A, was moved by clock-work at D, so that it was drawn over the surface of the large cylinder B, and wound on the surface of C. The electro-magnet was supported on a shelf or bracket, *h*. This magnet was employed to move the marking or printing lever, which was composed of an A-shaped pendulum, F, suspended, by its apex at *f*, from the top of the frame, immediately above the centre of the cylinder B. This lever was constructed of two thin rules of wood, meeting at the top at *f*, and about an inch apart at the bottom, where they were joined by a transverse bar, placed above the surface of the paper as it was moved over the surface of the large cylinder. A small lead-pencil, supported in a tube at *g*, was weighted so that its point was kept in contact with the surface of the paper. A soft iron armature was placed on the lever directly opposite the poles of the electro-magnet.

Stops on the frame at the side of the lever limited the distance through which it was able to move. The movement of the lever in one direction was obtained by the attraction of the electro-magnet for its armature, and in the opposite direction by the action of a weight. In subsequent instruments, Morse replaced this weight by a spring.

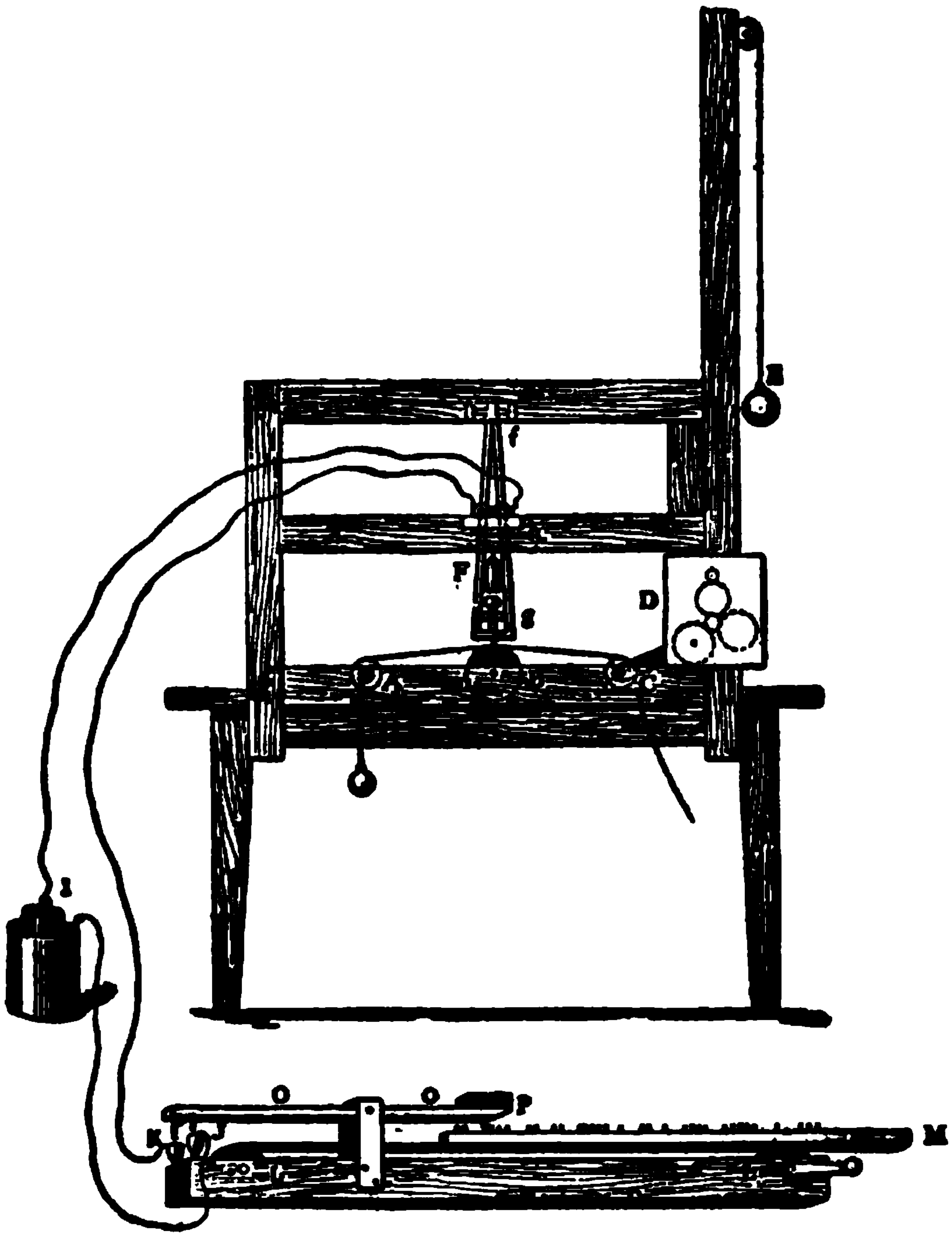


FIG. 97.—Morse's Early Telegraphic Instrument. Note the exceeding crude but quite efficient structure of the first electro-magnetic telegraphic instrument.

The electricity was obtained from a single voltaic cell at I. The circuit connections were as represented in the figure, there being interruptions at mercury cups J and K. The circuit was completed when a forked wire, on the lever O, O, connected

First crude telegraphic key.

the two cups by being dipped below the surface of the mercury on the depression of the lever. When the circuit was thus completed, the attraction on the armature at *h* drew the lever, F, toward the magnet.

Operation of the apparatus.

Now when the clock-work was put in motion, the paper ribbon was drawn over the surface of the cylinder B, and the pencil on the lever being maintained in contact with the ribbon, would be pulled to one side of the paper, tracing the line over it on a different part of the surface than when the current was not passing. In this way the paper would be marked, or would receive a permanent record on its surface of the impulses that had been sent over the line. Morse himself describes this action of the pencil as follows:

Morse's description of the recording.

"The pathway of the pencil-point (when the lever was attracted toward and held by the magnet for a longer or shorter time, tracing the lines) contains the three elements of points, spaces, and lines, forming by their various combinations the various conventional characters for numerals and letters. The other line, traced by the pencil when the lever is in its normal position, may, therefore, be disregarded. Only the variations in the line traced by the pencil when the magnet is charged are of importance."

In order to send the makes and breaks into the line so as to produce the arbitrary telegraphic characters, Morse employed the device represented at the bottom of Fig. 97. Here a crank, L, is provided for moving an endless band or tape. A grooved rule, M, arranged so as to hold a variety of metallic type, was placed on the moving band or ribbon, to which it was fixed by needle-points at-

tached to its lower surface. As this rule was moved by the band, the message previously set upon it by telegraphic types was transmitted over the line, as follows: As each projection on the type passes under the point P, of the lever O, O, the end of this lever is raised, thus completing the circuit by causing the wire to dip into the mercury cups. This completion of the circuit would, of course, produce marks on the paper. Some Morse telegraphic types, representing numerals, are shown in Fig. 98, while below them are represented the marks produced by the pencil, *g*, on a band of paper at the receiving end of the line.

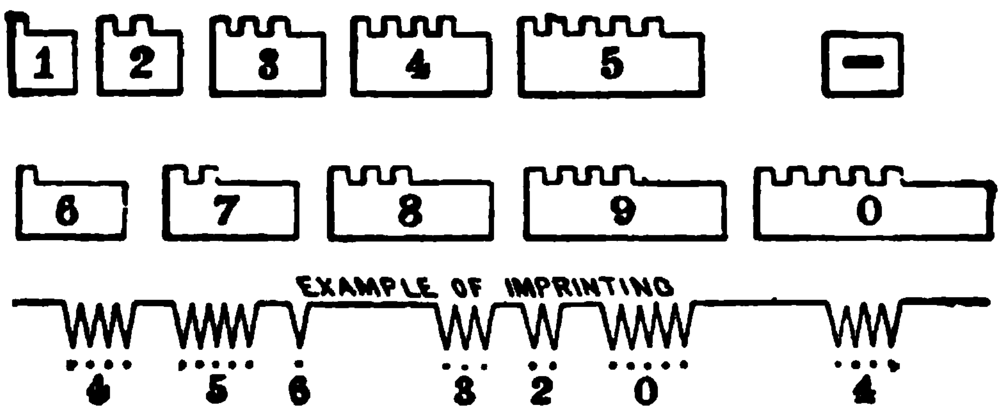


FIG. 98.—Morse Telegraph Type and the Imprinting or Record of Same.

Although exceedingly crude, Morse's early telegraphic recording instrument is practically identical, so far as the principles of its operation are concerned, with apparatus employed to-day. This will be readily seen, as has been pointed out by Prescott, from an examination of Fig. 99, where the pendulum lever of Fig. 97 has been prolonged above the fulcrum, *f*, and so furnished with a sharp stylus, *m*, that it is able simultaneously to mark the original Morse characters on the paper below at the same time that it marks the modern Morse characters on the paper above.

Morse's instrument and those of to-day identical.

On the 2d of September, 1837, Morse made a successful public exhibition of the apparatus shown in Fig. 97, during which he transmitted characters

Morse's exhibition of September 2, 1837.

over a line of wire one mile in length. He afterward greatly improved his apparatus, and eventually, after great hardships owing to poverty, succeeded in obtaining from the Congress of the United States an appropriation for the establishment of a telegraph line between Washington and Baltimore. The many difficulties Morse encountered before he was able to reach this result are so instructive that we

Telegraph line between Washington and Baltimore.

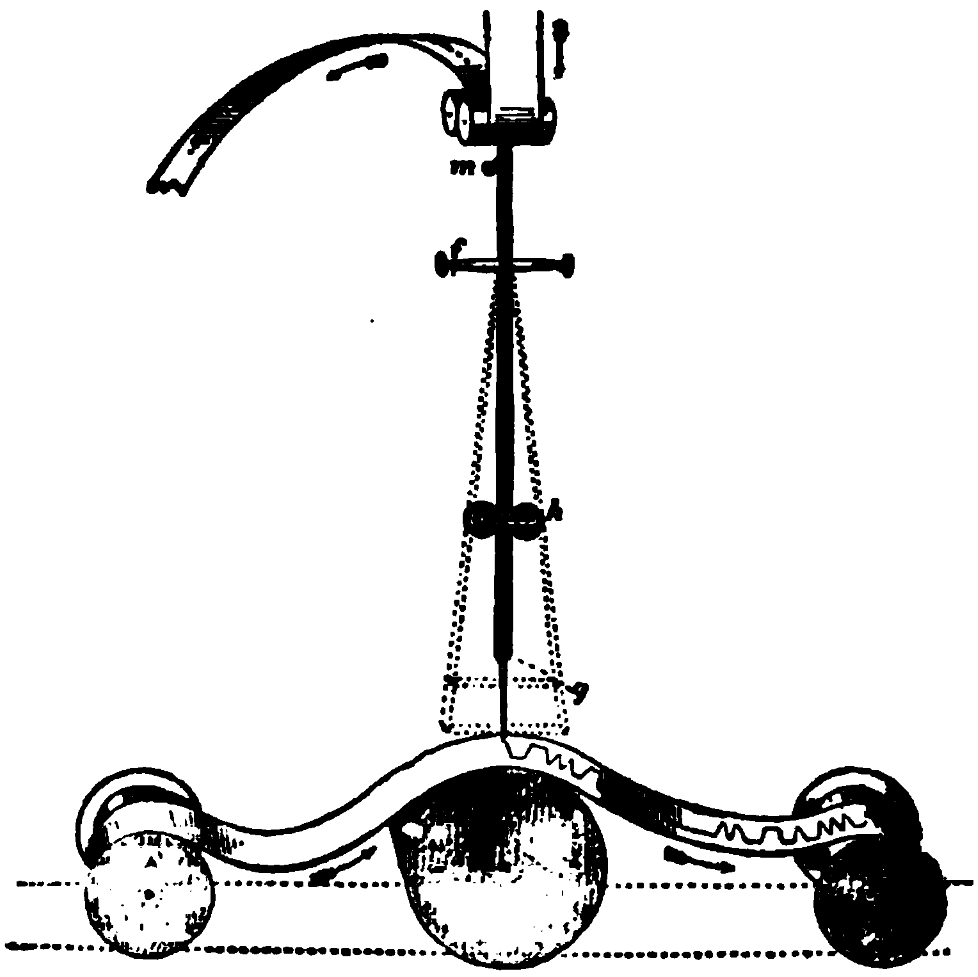


FIG. 99.—Close Resemblance of Morse's early Recording Instrument to that of To-day.

will briefly refer to some of them. Owing to his great poverty, he was unable to have his first crude apparatus put in such a shape as would warrant his publicly exhibiting it. He refers thus to these difficulties in a letter to a friend:

"Up to the autumn of 1837, my telegraphic apparatus existed in so rude a form that I felt reluctance to have it seen. My means were very limited, so limited as to preclude the possibility of constructing an apparatus of such mechanical finish as to war-

Unwilling to exhibit his crude apparatus.

rant my success in venturing upon its public exhibition. I had no wish to expose to ridicule the representative of so many hours of laborious thought. Prior to the summer of 1837, at which time Mr. Alfred Vail's attention became attracted to my telegraph, I depended upon my pencil for subsistence. Indeed, so straitened were my circumstances that in order to save time to carry out my invention, and to economize my scanty means, I had for months lodged and eaten in my studio, procuring my food in small quantities from some grocery, and preparing it myself. To conceal from my friends the stinted manner in which I lived, I was in the habit of bringing my food to my room in the evenings, and this was my mode of life for many years."

Morse's invention of the electro-magnetic relay.

The weary days and nights spent in careful thought over his apparatus, however, were not lost. It was during these times that Morse made his second great invention; viz., that of the telegraphic relay. The question often arose during conversations with his friends, as to whether there was not a limit to the power of a magnet in moving the lever of the recording instrument in the case of very long telegraph lines. The general conviction among Morse's friends, with whom he had conversed on the topic, appeared to be that such a limit would undoubtedly soon be reached; that although a magnet might possibly be made to operate at say a distance of 10 miles, or even of 20 miles, at greater distances, say of 100 miles, it would clearly become inoperative. To such objections, Morse made but one reply; viz., "If I can succeed in working a magnet 10 miles, I can go around the globe;" even adding, "It matters not how delicate the movement may be, if I can obtain it at all, it is all I want."

Morse himself thoroughly recognized the difficulty. He knew that some additional piece of apparatus was necessary in order to be able with certainty to establish telegraphic communication between two stations, separated by a distance of several hundred miles. At last he made the great invention of the telegraphic relay. But we will let Morse relate this part of the history of his invention:

Morse's account of his invention of the electro-magnetic relay.

"Between the date 1835, of the completion of the first instrument, and 1837, the date of its more public exhibition, there was a very important addition to it, which I had already devised and provided against a foreshadowed exigency, to meet it if it should occur when the conductors were extended, not to a few hundred feet in length in a room, but to stations many miles distant. I was not ignorant of the possibility that the electro-magnet might be so enfeebled, when charged from a great distance, as to be inoperative for direct printing. This possibility was a subject of much thought and anxiety long previous to the year 1836, long previous to my acquaintance or consultations with my friend, Professor Gale, on the subject, but I had then already conceived and drawn a plan for obviating it. The plan, however, was so simple that it scarcely needed a drawing to illustrate it; a few words sufficed to make it comprehended. If the magnet, say at twenty miles distant, became so enfeebled as to be unable to print directly, it yet might have power sufficient to close and open another circuit of twenty miles further, and so on until it reached the required station. This plan was often spoken of to friends previous to the year 1836, but early in January, 1836, after showing the original instrument in operation to my friend and colleague, Professor Gale, I imparted to him this plan of a relay battery and magnet to re-

solve his doubts regarding the practicability of my producing magnetic power sufficient to write at a distance."

The form assumed by the first telegraphic relay is seen in Fig. 100. Here a voltaic cell, 1, is placed at the end of a section of telegraph line of say 20 miles in length. The circuit of this cell extends an additional distance of 20 miles to the distant station, where, after passing through the coils of an electro-magnet, returns to the battery end of the line, and terminates in two wires connected with the end of a lever, C, over mercury cups, N and O. These two wires come near, but do not touch the surface of mercury in the cups. When the current arrives

Construction and operation of the electro-magnetic relay.

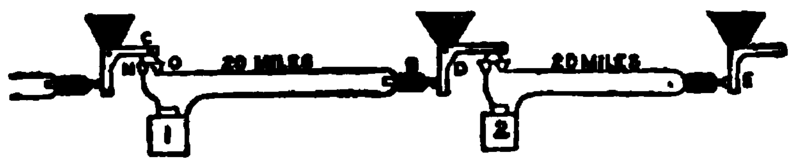


FIG. 100.—Morse's Relay. Note the fact that this early form of relay is substantially that employed to-day.

from the distant station over the line on the left hand, all it has to do is to attract the armature of the lever connected with C, thus closing the circuit of the battery 1, and repeating in the circuit on the right the signals that have been transmitted over the line on the left. In the same manner these signals arrive at B, connect the circuit of the battery 2, and cause the magnet at that end of the line to repeat what has been sent into the line E.

The relay invented by Morse was found to operate very satisfactorily in practice. In 1848, two Americans took some of the Morse telegraphic apparatus to Germany, with the view of constructing telegraph lines in that country. Not being able, at that time, to take out patents in Germany, they

Surprise in Germany at the excellent operation of the relay.

concealed the relay apparatus in a box. Neither Wheatstone nor Steinheil, to whose inventions we will shortly recur, had succeeded in obtaining very clear signals over a long line, owing to the want of a telegraphic relay. The Americans constructed a telegraph line between Hamburg and Cuxhaven, a distance of 90 miles. The excellent working of the line surprised the German electricians, and they vainly endeavored to ascertain the reason for the success. Steinheil himself subsequently visited one of the distant stations, and correctly assigned the reason for the success to some mechanism concealed in the relay box, which, however, the Americans refused to disclose. Afterward, Steinheil, having the operation explained to him, generously acknowledged to Morse the superiority of the latter's instrument over his own.

Appropriation of $30,000 for construction of telegraphic line between Washington and Baltimore.

Having at last perfected his apparatus, Morse now endeavored to obtain aid from the United States Congress, for the construction of a line between Washington and Baltimore. After many unsuccessful efforts, a bill was introduced into Congress appropriating $30,000 for this purpose. As in many similar cases, there was considerable opposition to the passage of the appropriation, and no little ridicule was made of the efforts to thus transmit intelligence. At last, however, the bill passed the House. Morse, who was an anxious spectator in the gallery of the House during the discussion of the bill, was advised by his friends to go home, and not submit himself to the disappointment that they believed he would unquestionably meet in the Senate, where it was believed a considerable majority was opposed to the passage of the bill. He took this advice, and we may, therefore, understand how greatly surprised the inventor was when he was visited

Final passage of bill.

by a Miss Elsworth, a daughter of the then United States Commissioner of Patents, who called the next day at the house where Morse was staying, and while the inventor was at breakfast congratulated him on the successful passage of the bill by the Senate. The young lady claimed of the inventor the fulfilment of a promise made to her that, if the bill were finally passed, the first telegraphic message sent over the line should be transmitted to her. This promise was faithfully kept, and Morse, when this line was finally completed, sent to her the now memorable message: "What hath God wrought."

Congratulations.

"What hath God wrought."

Fig. 101.—Recording Apparatus Employed on Line between Washington and Baltimore in 1857

Under the appropriation thus made by Congress, a telegraph line was constructed between Washington and Baltimore, and on the 27th day of May, 1844, the message above referred to was transmitted. The apparatus constructed for this purpose is represented in Fig. 101. The electro-magnet, M, assumed the form shown. This magnet was provided with an armature of soft iron, mounted on one end of a horizontal lever, L, fulcrumed at E. A train of clock-work, R, moved a band of paper, PP, over three steel points or styles, mounted on the end of

the lever L, so as to make indentations on the paper, and thus leave a permanent record of the message sent. Before this time Morse had abandoned the method of first setting up the message to be sent in telegraphic letters, and had substituted for it the telegraphic key represented at K, in the above figure.

The original arrangement of the circuits of this first telegraphic line will be better understood from an examination of Fig. 102, taken from Vol. I. of Prescott's work on "Electricity and the Electric Telegraph." Here the two cities, Baltimore and Washington, are represented by the letters B and W,

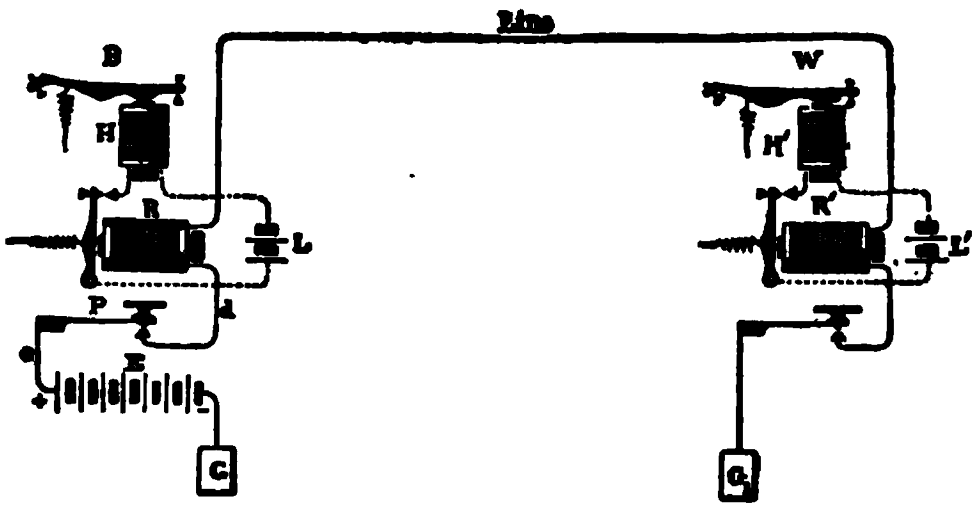


FIG. 102.—Arrangement of Morse's Circuits, showing Relay and Recording Magnet.

Operation of the relay

respectively. The battery, E, at B, is connected at one of its poles or terminals with the ground plate at G, sunk in the water of the bay, and the other pole to the transmitting key, P. The wire marked line extends between Baltimore and Washington on poles, through a distance of some 40 miles. At Washington, W, the battery has one of its poles or terminals grounded at G_1, through the key of the transmitter. Relays are shown at R and R′, placed in the closed circuit of the local batteries, L and L′, through the recording instruments, H and H′.

Such is the brief history of the first recording instrument. It differed from all telegraphic instru-

ments that had preceded it in the fact that the previous instruments were of the semaphoric type, as, for example, gas bubbles, the movements of magnetic needles, the reading of the signals depending on the reception of visual movements, which left no permanent record. Morse's method was the first by means of which a permanent record of the message received was obtained.

Wherein Morse's apparatus differed from previous apparatus.

It has sometimes been urged, as against the claims of Reis for the production of the first speaking telephone, that it was evident that he had not been able to produce an operative instrument, since, had he done so, it would almost certainly have been instantly employed in extended commercial use. It may be well to consider, in this connection, the many difficulties Morse had before he finally succeeded in establishing his great invention on a commercial scale. Even after he had demonstrated beyond any possibility of doubt that his apparatus was capable of successful commercial operation, he had difficulties, as already pointed out, in obtaining aid. Indeed, even after his line between Washington and Baltimore was successfully laid, and, indeed, after the same had been thrown open to public use on April 1, 1845, a reasonable doubt existed in the minds of many as to whether Morse had produced anything but a plaything, in proof of which note the actual returns during the first few days of the commercial use of this line. The charge established was one cent for every four words. The receipts during the first four days reached the magnificent sum of one cent. Then a marked increase of 12½ cents occurred in a single day; and finally the enormous sum of $1.32 was received in a single day. Let those who believe that the public is ever ready to instantly welcome a meritorious invention, bear

The small financial returns of the first commercial electromagnetic telegraph line.

in mind the lesson of the commercial receipts of the first operative electro-magnetic recording telegraph established in America.

The second of the telegraphic systems proposed during 1837 was that of Steinheil, of Munich, who had a telegraph of his construction in actual operation in July, 1837. Steinheil's telegraphic instruments were improvements on the telegraphic instruments invented at an earlier date by Gauss and Weber, who had erected telegraph lines over the tops of the houses at Göttingen, from the physical cabinet of the University to the Observatory, a distance of 1¼ miles. Neither of these gentlemen having sufficient time properly to improve the system of telegraphy they had devised, they had requested Steinheil to simplify the apparatus, so that it might be put into actual use. Since Steinheil's apparatus was based on improvements in the Gauss and Weber apparatus, it will be necessary briefly to examine into some of the characteristics of the earlier apparatus.

Steinheil's apparatus of 1837.

The telegraphic apparatus of Gauss and Weber, invented in 1833, was based for its operation on the deflections of a magnetic needle, produced by a coil of insulated wire, through which the currents transmitted over the telegraphic line were sent. No voltaic battery was used in this telegraphic system, since the inventors had availed themselves of the principle of magneto-electric induction, discovered by Faraday in 1831. The transmitting instrument consisted of a magneto-electric generator operated by hand. It was formed of a hollow standard, *a*, Fig. 103, containing three powerful permanent steel bar magnets, *n*, *s*, each weighing 75 lb., with a coil, *d*, of some 7,000 turns of insulated wire rest-

Gauss and Weber's telegraphic apparatus of 1833.

Gauss and Weber's transmitter.

ing on the top of the stool, P P, so as to surround the magnet poles. This coil was provided with handles at *b*, *b*. In transmitting signals, the operator took hold of the handles, and, raising the coil, produced a current flowing in a certain direction; but, while lowering it, produced a current flowing in the opposite direction. These movements corresponded to the movements of the key of the transmitting instrument.

FIG. 103.—Gauss and Weber's Electro-magnetic Telegraph Transmitter. Note the clumsy form of magneto-electric generators employed for sending electric impulses into the line.

The receiving instrument of Gauss and Weber's telegraph is represented in Fig. 104. The current from the transmitting station is received over the line wires — and +, passes through the coil of insulated wire *m m*, and causes a deflection of a heavy bar magnetic needle, M M, suspended by means of silk threads to the wall of the room. A mirror, N, suitably attached to a rod, K, and connected with the magnet M M, is moved to the right or left by variations in the direction of the current from the transmitting end of the line. By the aid of a telescope at R, these movements of the magnet are readily seen by observing the movements of a spot of light on a scale, S S, placed in such a position

Gauss and Weber's receiving instrument.

that its image can be readily seen through the telescope in the mirror N. The alphabet designed for use in this instrument was arranged by various numbers of deflections of the needle to the right and the left. This method of receiving telegraphic signals by the movements of a delicately suspended magnetic mirror is practically the same as that now employed in systems of cable telegraphy.

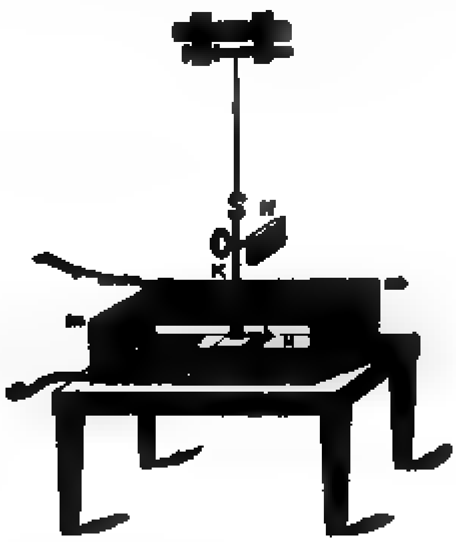


FIG. 104.—Gauss and Weber's Electro-magnetic Telegraph Receiver.

Steinheil's improved form of transmitting instruments.

Steinheil improved the instruments of Gauss and Weber to so great an extent that his apparatus might also be considered as a distinct invention. His improvement in the transmitting instrument consisted in the employment of some 17 separate horseshoe magnets, provided with two separate induction coils, having a combined length of some 15,000 turns. These induction coils were so mounted that they turned on an arbor, and presented in rotation the axes of the coils to the poles of the magnet, so that when one coil was under, say, the north pole of the magnet, the other end was under its south pole. Moreover, the commutator connected with these coils was so arranged that when one of the coils was turned in one direction, say from right to left, the

alternating currents produced in a certain direction only were permitted to enter the line; while when turned in the opposite direction, only the current of opposite polarity was permitted to pass to the line, the other being cut off.

Steinheil's improved receiving instrument.

Steinheil improved the receiving instrument of Gauss and Weber by arranging for a permanent record of the movements of the magnetic needle, thus doing away with the observation through the telescope. He accomplished this as follows: The receiving instrument consisted of a flat coil of wire

FIG. 105.—Steinheil's Improved Receiving Instrument. Note how markedly this differs from the instrument of Gauss and Weber.

of some 600 turns, represented in Fig. 105, in a vertical cross-section at *a b*. In the centre of this coil two separate magnetic needles, *n s* and *n′ s′*, were pivoted separately at *m* and *m′*, with their opposite poles facing each other. These magnets were furnished at *s* and *n′*, respectively, with minute reservoirs, containing ink. Small capillary tubes, *c* and *c′*, connected with these reservoirs, had their

free ends open, and brought near a paper fillet that was maintained in motion by the aid of suitable clock-work, so that they would leave ink marks on the paper corresponding to the impulses sent over the line. Stops were placed at *h* and *h'*, which limited the motion of the needles, so that a current sent through the coil *a b*, in one direction, would move only one of the needles, and one sent through the line in the opposite direction would move the other needle only.

Steinheil's electro-magnetic recording apparatus.

It was while making the experiments necessary for the improvement of these instruments, that Steinheil discovered the fact that a return wire is not necessary in the case of telegraphic instruments, but that the ground can be employed in place of such return. He had, before the time of this discovery, employed a metallic circuit, but now removed it. Sabine, in his work on the "Electric Telegraph," thus speaks of Steinheil's discovery:

Steinheil's discovery of the ground return.

"When experimenting on the Nuernburg and Feurther Railway, to ascertain if the rails could not be made use of as lines for the service of a telegraph, Steinheil made the important discovery that the earth might be used as part of the circuit of an electric current. This discovery, which ranks with those of Volta and Oersted, was one of the greatest contributions ever made to the progress of the telegraph. Had the identity of the electricities been known earlier, return circuits other than the earth for voltaic currents would never have been used; for in all the earlier experiments and attempts with frictional electricity, the earth was used as the return circuit.

Sabine on Steinheil's discovery of the earth return.

"Steinheil took advantage of his discovery, and removed the halves of his lines, leading, in their stead, the corresponding connections of his apparatus to plates of metal buried in the earth."

While acknowledging the great value of this discovery of Steinheil, we do not deem it worthy to be accorded the very high importance indicated in the above quotation, since it was well known that the earth was capable of acting as a return circuit. The frictional electric telegraph lines, alluded to in connection with the early history of the telegraph, employed such return circuits, and even admitting that it was not at Steinheil's time certainly known that all electricity was one and the same, no matter what its source, yet it does not seem to be so great a discovery to use the earth as a return circuit in this particular case.

Prior use of earth returns in earlier telegraphs.

We come now to the third great invention of 1837; *i.e.*, that of Cooke and Wheatstone. These inventors described their invention in an application that was sealed in the English Patent Office on June 12, 1837. In the receiving instrument of this telegraph five separate magnetic needles were arranged in a vertical position over a dial, on which were marked the letters of the alphabet and the numerals, as shown in Fig. 106. These needles were so acted on by currents passing through coils of insulated wire placed behind them, through the action of keys, shown at the bottom of the figure, that two of such needles would point to a letter situated on the dial at or near their point of intersection. Mr. Wheatstone thus describes his invention in his examination before the Parliamentary Committee on Railways:

Cooke and Wheatstone's British patent of June 12, 1837

"Upon a dial are arranged five magnetic needles in a vertical position; twenty letters of the alphabet are marked upon the face of the dial, and the various letters are indicated by the mutual convergence of two needles when they are caused to move. These magnetic needles are acted upon by electrical cur-

Wheatstone's description of his receiving telegraph.

rents passing through coils of wire placed immediately behind them. Each of the coils forms a portion of a communicating wire which may extend to any distance whatever; these wires at their termination are connected with an apparatus, K, which may be called a communicator, because by means of it the signals are communicated. It consists of five longi-

FIG. 106.— Cooke and Wheatstone's Five-needle Electro-magnetic Telegraph.

tudinal and two transverse metal bars, fixed in a wooden frame; the latter are united to the poles of a voltaic battery, and in the ordinary condition of the instrument, have no metallic communication with the longitudinal bars which are each immediately connected with a different wire of the line; on each of these longitudinal bars, two stops are placed, forming together two parallel rows. When a stop of the upper row is pressed down, the bar upon

which it is placed forms metallic communication with the transverse bar below it, which is connected with one of the poles of the battery; and when one of the stops of the lower row is touched, another of the longitudinal bars forms a metallic communication with the other pole of the voltaic battery; and the current flows through the two wires connected with the longitudinal bars to whatever distance they may be extended, passing up one and down the other, provided they be connected together at their opposite extremities, and affecting magnetic needles placed before the coils, which are interposed in the circuit."

FIG. 107.—Cooke and Wheatstone's Single-needle Telegraph.

In subsequent inventions, Cooke and Wheatstone greatly improved their telegraphic instruments. In these improvements they finally replaced the five-needle telegraph by a single-needle telegraph, and took out a number of patents in England for these inventions. One of these, of May 16, 1845, de- **Cooke and Wheatstone's single-needle telegraphic receiver.**

scribes the single-needle telegraph receiving instrument represented in Fig. 107. Here a single coil of insulated wire only is employed, a single vertical magnetic needle being suspended within such a coil, so as to freely turn to the right or to the left, according to the direction of the current through the coil of wire. The movements of this needle were visible from the outside of a dial plate, on which were marked the letters and numerals, though only for the sake of reference.

Wheatstone's printing device.

In a subsequent improvement of his apparatus, Wheatstone devised a plan whereby the letters were printed on a fillet of paper instead of being merely indicated to the eye by the pointing of magnetic needles.

CHAPTER XIV

TELEGRAPHIC LINES

"To the intelligent and observant mind of youth, the art of telegraphy possesses a singular fascination, and in many instances its pursuit tends to excite a spirit of scientific inquiry, not only commendable in itself, but valuable as establishing a sure foundation for future success in broader fields of labor."—*The Electric Telegraph:* Pope

UNLIKE the telephonic circuit, the telegraphic circuit, as generally employed to-day, employs a ground return; for, the telegraphic receiving apparatus is far less sensitive than the telephonic receiver, so that there is comparatively little trouble experienced from induction from neighboring lines in the way of telegraphic "cross-talk." **Telegraphic cross-talk.**

In all cases where the earth is employed for a return circuit, it is necessary to connect the ends of the return wires to plates, called ground plates, which, as in the case of the telephonic circuit, are necessarily buried to a depth sufficiently great to meet with permanently moist earth. It might be supposed that, since the materials of which the earth is composed generally possess a high electric resistance when in small masses, that the use of an earth or ground return would necessarily greatly increase the total resistance of the telegraphic line. It must not be forgotten, however, that the resistance of a conductor decreases with the area of its cross-section, and that, therefore, provided the ground plates make a good contact with the earth, practically the entire mass of the earth is employed **Why the resistance of the ground return is so small.**

for the return circuit. In such a case, from the great area of cross-section, the resistance thus introduced into the telegraphic circuit is comparatively insignificant.

It will not answer, however, carelessly to insert the earth plates in the ground. Unless the telegraphic line be provided with suitably grounded earth plates, satisfactory working becomes impossible. It is necessary to ensure a good earth, that is, a good contact between the earth and the plates, and it is for this reason that the plates should be sunk far enough into the earth to meet with strata that are moist even during dry weather. Wherever it can be readily done, the earth wire should be connected with the iron gas or water pipes, since the extended surfaces of these metallic masses are so great as to ensure an excellent ground. Where this can not be done, the plate should be buried as before recommended.

Necessity for ensuring good contact of earth plates

In all cases where the telegraphic instruments are of such construction as to be readily affected by very weak electric currents, the two ground plates employed at opposite ends of the line should be made of the same metal; for example, they either should be both of copper, or both of galvanized iron, and not one of copper and one of galvanized iron; since, under such latter circumstances, there would be a constant electric current produced from the two plates acting as a species of voltaic cell, the moisture in the earth forming the electrolyte. In such case a constant electric current would traverse the line, that might be capable of affecting the delicate adjustment of the instruments.

Both earth plates must be formed of same kind of metal.

Telegraph wires or lines are either overhead or underground. As a rule underground wires are only

employed where, as in the case of large cities, the laws forbid the use of overhead wires. In such cases, a number of separate wires or conductors, sometimes as many as fifty or over, are wrapped in the form of a cable, as represented in Fig. 108. Here, as will be seen, the separate wires are wrapped around a central wire in regular layers, the separate layers being distinguished from one another by some peculiar marking placed on one of the insulated wires in each layer, as is indicated in the figure. This is done for the purpose of readily distinguishing the separate lines in testing, jointing, etc. The separate wires are insulated by some suitable insulator, but, in this country, in the case of underground

Underground telegraphic cable.

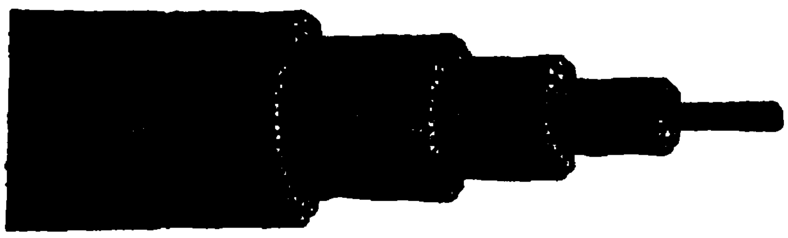


FIG. 108.—Telegraph Cable for Underground Line. Note the manner in which the separate layers of insulated conducting wires are placed over one another.

wires passing through large cities, gutta-percha, although an excellent insulator, is not employed, for the reason that it possesses a very low melting point or softening point; viz., as low as 135° F. This temperature is apt to occur in the streets of large cities, where boilers or furnaces may occupy the space below the pavement.

The telegraphic cables are generally laid in underground conduits, containing ducts, and provided at suitable intervals with manholes, for ease in introducing or removing the cables. In the early history of the art, such wires were frequently buried in cement or asphalt, but the difficulties arising from their removal for correcting a fault or break were

Underground conduits with ducts and manholes.

so great that the conduit plan with ducts is now universally employed.

Wherever it is possible, however, telegraph lines are overhead lines, and consist of bare wires or conductors, that are supported on insulators placed on brackets on wooden or other poles. There are two objections to the use of underground telegraph conductors, which render aërial conductors far preferable for telegraphic communication, and this, irrespective of the matter of expense, which, of course, is far greater in the case of underground wires. In the first place, it is much more difficult to determine the exact location of a fault or break in an underground telegraphic wire than it is in the case of an overhead conductor. It is true that, to a great extent, this difficulty is obviated by a good system of underground conduits, with manholes placed at suitable intervals. Then again, when such a line is properly installed, there should be comparatively few breaks or faults, so that the necessity for repairs would necessarily be far less in an underground system than in the case of overhead wires, where a single sleet or wind storm might throw down almost the entire system. If, then, the only objection were the difficulty of repairing and testing the wire, it would not prove so serious a difficulty.

Serious objections to underground wires.

But there is an objection to the use of underground conductors which is of a far more formidable character, since it relates to the electro-static capacity of the telegraph line. If this capacity be too great, there will be a retardation in the speed of signalling, which will necessarily greatly decrease the usefulness of the telegraph line for the use of high-speed telegraphy, where it is necessary that the different impulses sent over the line shall follow one another

with great rapidity. Now the electro-static capacity of a telegraph line will rapidly increase when the wire is placed near the earth, as, of course, it will necessarily be in the case of an underground cable. Before an electric impulse sent into a telegraph line is able to affect the receiving instrument at a distant station, it must charge the surface of the entire line. Moreover, this charge must disappear before another charge can be sent into the line. Where, as in the case of a long line, there is a sensible leakage or loss of current at the insulators or elsewhere, there will be, up to a certain limit, an increase in the speed with which the line can be charged and discharged, and, consequently, in the speed of signalling. Such leakage, however, must never be so great as to render the current strength at the receiving end of the line too feeble properly to operate the receiving instruments. Now it is clear that, in an overhead line, where the wires can be placed at fairly considerable distances above the ground, the electro-static capacity will be much less, and, consequently, the speed of signalling greater, than in the case of any underground conductor.

Increased electro-static capacity of underground conductors

The line wires or conductors are either galvanized iron or hard-drawn copper wire. The latter is coming into use in the United States and elsewhere, owing to its greater conducting power. Where copper wires are employed, No. 14, of the B.W.G. (Birmingham Wire Gauge) is generally used; while No. 6, of the same gauge, of iron wire is used. Where a great number of copper wires are suspended from the same poles, it is customary, for the purpose of strengthening the line, to employ one or more iron wires. If only one such wire is used, it is generally placed at the top of the poles. Where several are employed, the iron wires are placed on cables at the

Copper line wires vs. iron line wires.

side of the poles, either on every cross arm, or on every alternate cross arm. In this way the line is greatly stiffened, and is better able to withstand the action of heavy winds.

Telegraphic poles.

Telegraphic wires are supported by poles made either of wood or iron. Although iron poles are much more desirable than wooden poles, yet, in the case of the breakage of an insulator, the line is more readily grounded by coming in contact with the iron pole than it would if a wooden pole was used.

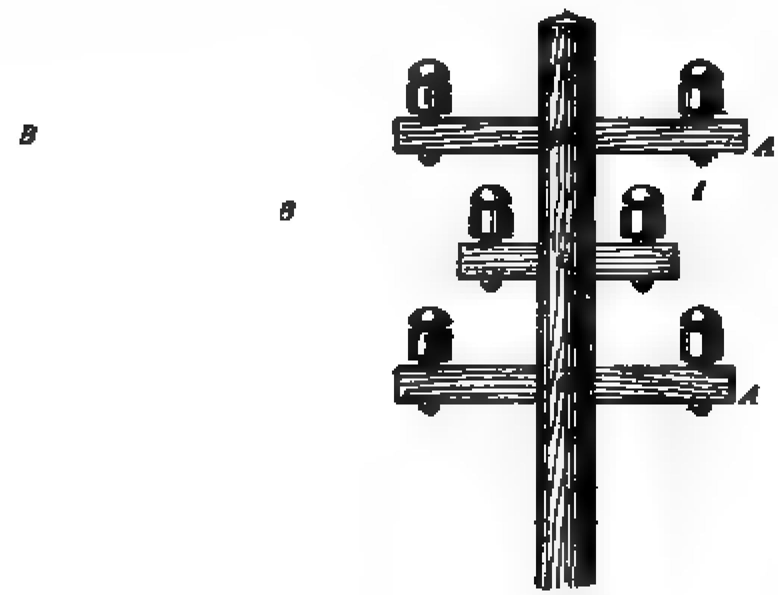


Fig. 109.—Wooden Telegraph Pole, with Cross Arms, Brackets, Pins, and Insulators.

A common form of wooden pole employed on telegraph lines is shown in Fig. 109. The height and diameter of the pole depend on the number of wires it is intended to support. The poles are carefully placed in the ground to such a depth as will enable them to withstand the action of the wind, etc. In order to prevent rapid decay, care must be taken to see that the wood is well seasoned. Where the poles are placed on curves or at sudden bends, they should be set in an inclined or slanted position, in order to better withstand the pull produced by the weight of the wires.

The poles shown in the above figure are furnished with cross arms A, A, or brackets B, B, provided with pins *i*, *i*, in the well-known manner. These pins have a screw thread at their upper part, for the re-

FIG. 110.—Glass Insulator for Telegraph Line. This is a very common form of insulator for telegraphic line wires.

ception of a threaded glass or porcelain insulator. In Fig. 110, one of the many forms of such glass insulators is represented.

Tie-wire for securing line-wire to insulator.

The depth of the groove on the insulator is a matter of considerable importance; for, if too shallow, the wire may readily come off, while if too deep, the strain on the wire may result in crushing the edge of the glass insulator, and thus injuring its insulat-

FIG. 111.—Method of Securing Line Wire to Insulator by Tie-wire.

ing power. The line wires are passed around a part of the insulator, and secured to it by a piece of tie-wire of iron, in the manner shown in Fig. 111. Where the line is of iron, the tie-wire must be formed

of iron, and where of copper, it should be formed of copper; otherwise, a galvanic action is apt to occur under the influence of the moisture of the air, and the iron wire will be rapidly corroded.

Telegraphic joints.

Where the ends of two circuit wires are to be connected together, various methods are employed in

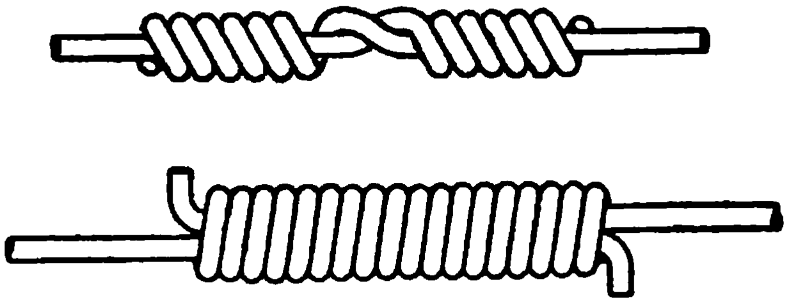


FIG. 112.—Some Forms of Telegraphic Joints. Note the different winding of the wire in these joints.

American twist joint.

Britannic joint.

order to ensure a joint of low resistance. Two different methods are shown in Fig. 112. In the method represented at the top of the figure, a form known as the American twist joint is seen, where two wires are wrapped upon each other in the manner shown, and afterward soldered together. In the joint shown at the bottom of the figure, known as the Britannia joint, the two ends of the wire are laid

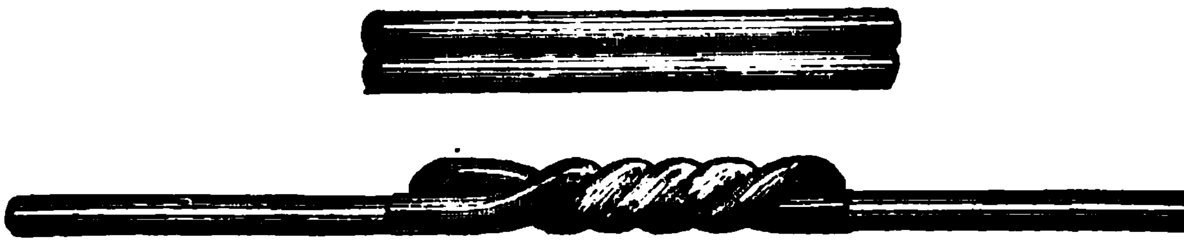


FIG. 113.—McIntyre's Parallel Sleeve Telegraphic Joint. Note the position of the parallel sleeves before and after twisting.

McIntyre parallel sleeve joint

side by side, and then bound together by a separate piece of wire, and, as in the American twist joint, are then soldered together. In the form of joint represented in Fig. 113, called the McIntyre joint, the ends of the wires are inserted in parallel sleeves or tubes, represented at the top of the figure, and are

then twisted together as shown in the lower part of the figure. In this case, soldering is not required.

House-top fixture and cable-head.

Where the wires pass over the top of a house, they are secured to an ordinary glass insulator, placed on a suitable bracket. Where a number of such wires, however, pass across the house, it is necessary to provide a special fixture called a house-top fixture. This is provided with cross arms and insulators, as represented in Fig. 114. When this fixture is ap-

FIG. 114.—House-top Fixture

plied to the case of the wires passing from an underground cable to an overhead conductor, as in the similar case of a telephone circuit, a cable-head or cable-box is employed.

Effect of insulation on conductivity of a telegraph line.

There are two properties that all telegraph lines should possess, in order to ensure efficient operation; viz., a low electric resistance, and a high insulation. A low electric resistance of the conducting lines, or, as it is more frequently called, a high conductivity of the line, is a matter of the greatest importance. For this reason copper wire is generally employed

instead of iron wire, as already mentioned. But the conductivity of a telegraph line is necessarily dependent on the degree of its insulation. If this be poor, there will, of course, be a poor conductivity of the line, as indicated by the strength of the current which arrives at the receiving end. Perhaps most of the difficulties that occur on telegraph lines are due to the escape of current from poor insulators. The wonderful growth of the telegraphic service in all parts of the world necessitates, in large cities or in their neighborhood, the installation of a very great number of telegraph wires on a single pole line. With this increase in the number of wires there occurs an increased difficulty in obtaining the requisite high insulation.

Since the insulating power of air is very high, the bare telegraphic wires can be safely employed suspended on pole lines, as already described. The glass insulators generally used possess very high insulation, on account of their high electric resistance, so that but little current can pass through them from the wire to the ground as long as the weather is clear. During stormy and foggy weather, however, there may be an increased loss of current at the insulators, especially if they have become covered with small particles of dust or soot from chimneys where bituminous coal is burned, these substances coating the surface of the insulator with conducting particles that tend considerably to increase the loss of current by leakage. The outside surfaces of insulators, however, are generally so shaped as to enable the rains to cleanse and wash off the dirt, and then to drain directly off to the ground, rather than run down the poles.

Effect of dust and soot on efficiency of insulators.

But while the individual resistance of a single insulator may be very high, being frequently from

9,000,000 to 15,000,000 ohms, yet, in a long wire, where there are a great number of such insulators, the total insulation of the line will be the joint resistance of all these insulators; *i.e.*, the resistance they would have as a number of parallel connected resistances. Every insulator, therefore, added to a telegraph line, decreases the insulation resistance of the line. The joint resistance of a telegraph line, as is produced under the influence of the various points of escape of the current offered by the insulators, is in the neighborhood of 300,000 to 500,000 ohms for each mile of wire, so that, if there were thirty insulators on this part of the line, each of the insulators would require to have the resistance above mentioned; viz., from 9,000,000 to 15,000,000 ohms. The resistance of the insulators, however, varies very rapidly under different conditions, being high in clear warm weather, when the sun is shining brightly and the air is dry, and much lower during damp foggy weather. In addition to the loss of current through the insulators, considerable difficulties often arise from leaves and branches of trees coming in contact with the bare wire, so that, in this way, the insulation resistance of a line may be considerably affected. There are also troubles in the neighborhood of large cities, that arise from the strings of kites becoming entangled in the wire, thus permitting currents to pass between neighboring wires. Of course, during storms, if a single wire should break, it would establish contact with the neighboring wires that would probably throw a great number of circuits out of use.

Joint resistance of telegraph line, or total insulation of line.

Leakage due to leaves and branches of trees.

Since there is always a considerable loss of current on long telegraph lines, that prevents the current from the sending end of the line reaching the receiving end in the degree of strength necessary

Strength of working current on line wires.

for the proper action of the receiving instruments, it is generally necessary to employ currents of considerable strength on such lines. There is, however, a limit to the strength of current that can be so employed in certain cases, especially in the case of cable telegraphy, to which we will soon refer.

Difficulties in underground lines.

In the early history of telegraphy, underground lines were employed, but many difficulties were experienced, owing to the tendency of the insulation to fail. Morse's first telegraphic line between Washington and Baltimore was commenced as an underground line, but, fortunately, a change was made in the plans before the line was completely installed. In 1853, a line was erected in England by the Magnetic Telegraph Company, in which copper wires, insulated with gutta-percha, were employed. This line was quite successful for a while, but afterward failed. Concerning its failure, Prescott writes as follows:

Prescott on the many causes of failure in gutta-percha insulated underground telegraph wires.

"Before the work was finished a great number of faults were found, generally due to nailing on the cover, the nails frequently being driven into the gutta-percha. A long length of line had all its nails renewed, and the boarding bound with wire. A few years after the completion of the work the wires continually failed, and when a fault was located in any wire the cable was opened and a good wire substituted for the faulty one. Subsequently the line was tested in five-mile sections, and when any section was found defective it was replaced by an overhead line, and the underground cable removed. This course gradually resulted in the replacement of the line by an overhead one, until at length none of the original work was left. The faults which appear to have caused the abandonment of the gutta-percha cables were the drying up and cracking of

the gutta-percha in sandy ground; the rotting of the gutta-percha in dirty, stagnant water; the formation of fungi on the gutta-percha near oak trees; the destruction of the gutta-percha by gas water near gas pipes; the burning of the gutta-percha by the carelessness of the workmen engaged in laying it; the rotting of the gutta-percha under the lead numbers (*i.e.* lead tags fixed to the wire for identification), and the pricking of the wires and omitting to seal the places up."

It will be noticed in the above quotation that there is an unfortunate property possessed by gutta-percha to answer well at first, so far as its insulating powers are concerned, and then gradually to fail from a variety of circumstances. This peculiarity led to considerable difficulty in Germany. In 1847, Dr. Werner Siemens, having satisfied himself of the admirable qualities possessed by gutta-percha as an insulator, employed it for covering the wires in an underground line laid from Berlin to a neighboring town, at a distance of some five English miles. This line maintained its resistance so well that, during the following years, a number of lines were constructed, until some 3,000 miles of insulated gutta-percha wires were laid underground. These lines were quite successful for the first few years, but, like the English lines, they finally failed, and were replaced by overhead lines.

Extensive use of gutta-percha in underground wires in Germany.

CHAPTER XV

THE ELECTRO-MAGNETIC TELEGRAPH OF TO-DAY

"The telegraphic Tory, who sees virtue in the tape, and believes in the greater accuracy of a record, still exists in large numbers in various parts of Europe, but he has disappeared from the United States of America and from England. The ear is more accurate than the eye, and more rapid in deciphering these fleeting signals that convey language."—*Preece: Address,* 1893

The closed-circuited and the open-circuited Morse telegraphic systems.

THE Morse telegraphic system is practically the system generally employed to-day both in America and Europe. The system, however, employed in America differs from that employed in Europe. The American system is a closed-circuited system, in which the batteries and instruments are placed in a closed or completed circuit when not in use, while in Europe generally the batteries are out of the circuit while the line is not in use, or the system is an open-circuited system. In this latter system, however, the instruments in the stations are in closed circuit in the line at all times. The transmitting and receiving apparatus employed on the line are practically the same in both systems. In the closed-circuited system there is generally a large battery employed at each end of the line, while in the open-circuited system a separate battery is necessary at each station. It will be interesting, therefore, to examine in some little detail the peculiarities of both of these systems. To do this we must first discuss the apparatus employed on the ordinary electro-magnetic telegraph, as it is used in both countries. This apparatus consists es-

sentially of a transmitting key, a receiving relay, and of a sounder, or some form of recording apparatus.

Morse telegraphic key

The transmitting key assumes a variety of forms. They are all, however, practically like that represented in Fig. 115. Here a brass lever, A, some four or five inches in length, is furnished at one end with a knob or button, B, of hard rubber, or other insulating material. This lever is movable to and fro through a short vertical distance by means of a horizontal axis at G, which turns between two adjustable set screws, D, D. The extent of this ver-

FIG. 115.—Morse Telegraphic Key for Closed-circuited System.

tical movement is limited in one direction by an anvil, C, and in the opposite direction by a set screw, F. During the up-and-down movements of the lever A, contact is made and broken between a platinum stud, or contact piece placed on the lower side of the lever A, and a similar stud or contact piece placed on the anvil C. These contacts are made of platinum in order to avoid the oxidation that might otherwise take place by reason of the small arc formed on breaking the circuit of the telegraph line. The key is moved downward by the hand of the operator, but when released is moved back by the action of a spring placed under the lever, the extent of motion of the key being regulated by means of a set screw at F_1.

The transmitting key is attached to the table in the telegraph office by means of long screws, L, L, that pass through it, the circuit wires being connected with the key by bending the ends of the wires and clamping them between the nuts K, K, and the under side of the table. The platinum contact on the anvil at C is connected with the wire at L, on the left-hand side of the figure, but insulated from the metallic framework of the key. The other wire is connected directly with the metallic frame of the key, and, therefore, with the upper contact on the lower side of the key. The key represented in this figure is designed for use in the closed-circuited system, so that a switch is provided at H, by means of which the line can be closed when the particular station is not in use.

Circuit connections of telegraphic key.

FIG. 116.—Morse Receiving Magnet or Relay. Note the small amount of work that is required to be done by the electro-magnet M in order to operate the receiving magnet or relay.

The essential part of the receiving magnet or relay consists of a readily movable armature, whose only function is to close and open, by its to-and-fro movements, the circuit of a local battery containing a receiving instrument, such as a sounder or some recording instrument. A form of receiving relay in common use is shown in Fig. 116, where M is an electro-magnet of the horseshoe type, whose cores are wound with a great length of insulated wire. The form represented in the figure is that commonly employed by the Western Union Telegraph Com-

Morse receiving magnet or relay.

pany. In some of these instruments the magnet coils consist of some 8,000 separate turns of No. 32 copper wire, having a diameter of .009 inches, and a total electric resistance of about 150 ohms.

All the work the telegraphic relay has to do is to open and close a set of contact points between *a* and F. This it does by means of the movements of an armature of soft iron, A, attached to a vertical lever, *a*, whose lower end is mounted on a steel arbor, moving between the two adjustable set screws shown. The usual platinum contacts are placed on the contacts between *a* and F. The movement of the armature in one direction is effected by the attraction of the electro-magnet M, while its movement in the opposite direction is obtained by the action of a long coiled spring, S′, whose tension is regulated by means of the screw S.

Contacts of receiving magnet or relay.

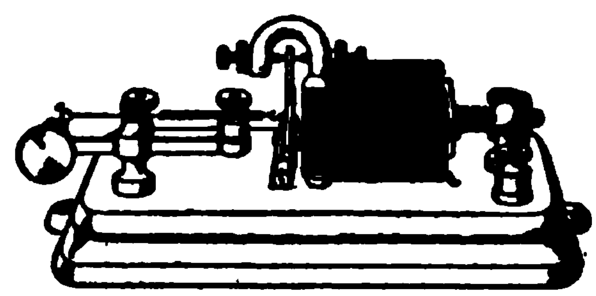


FIG. 117.—A Form of the Western Union Company's Receiving Magnet or Relay. Note the slight difference in this relay from that shown in the preceding figure.

A great number of different forms have been given to the receiving relay, one of these, employed by the Western Union Telegraph Company, being that shown in Fig. 117. Instruments of this type are now made in which the resistances of the coils of the electro-magnets are either 150 ohms, 200 ohms, or 300 ohms.

Another form of receiving magnet or relay.

We have already explained, in connection with the early history of the telegraph, just what happens when the relay of the receiving magnet closes the contacts at the receiving end of the line. It may

be well, however, to examine Fig. 118, to see, perhaps, more clearly just how the closing of the contact points at *a* and F, in Fig. 116, is able to throw into action the sounder or other receiving instrument through the agency of a local battery. In Fig. 118, R represents the relay magnet, L its armature, and t_1 and t_2 the contact points. From this figure it will readily be understood that whenever the contacts t_1 and t_2 are closed, the circuit of the local battery, *e*, is completed through the sounder S, so that its armature is drawn toward the magnet poles; and that on the other hand, whenever the con-

Action of relay contacts on circuit of local battery and sounder or recorder.

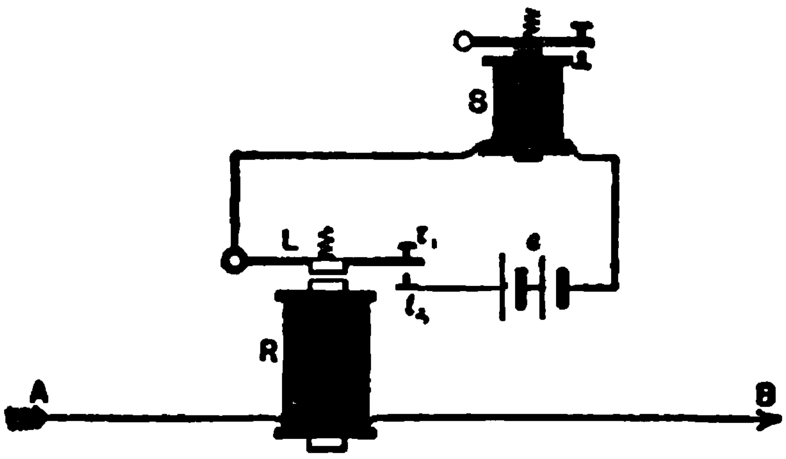


FIG. 118.—Diagrammatic Representation of Circuits of Telegraphic Relay and Sounder. Note the connection between the local battery, contact points, and sounder.

tacts at t_1 and t_2 are broken, by the action of the opposing spring, the armature is drawn back in the opposite direction.

There now only remains to examine the construction and operation of the sounder or other receiving instrument employed at the receiving end of the line. Morse's original plan was to construct a recording apparatus, so that the different messages sent over the line wire were recorded in a permanent manner. It was soon discovered, however, that such a recording instrument was unnecessary. The operator rapidly learned to receive the messages sent by the various sounds produced by the recording instru-

Messages read by sound; recorders unnecessary.

ments, so that he could write the message directly on a slip of paper without being obliged to transcribe it from the record slip. These sounds were produced by the movement of the armature of the recording magnet in one direction under the influence of the electro-magnet, and in the opposite direction under the influence of the opposing spring. In most offices to-day, therefore, the receiving magnet has been replaced by an apparatus known as the Morse sounder. Since the letters or characters of the Morse telegraphic alphabet consist of various dots and dashes,

The Morse sounder.

FIG. 119.—The Western Union Company's Form of Morse Telegraphic Sounder. Note the position of the striking lever and its limiting stops.

separated from one another by certain intervals, it might be thought that the sound produced by a dot would be indistinguishable from that produced by a dash; but this difficulty does not exist, since it is rather the interval of time between successive sounds than the sounds themselves that give to them their distinctive characteristics.

A form of Morse sounder employed by the Western Union Telegraph Company is represented in Fig. 119. Here the electro-magnet is provided with an armature mounted on a horizontal lever, and

pivoted at one end, so as to be capable of motion to-and-fro through a slight vertical distance. This motion is limited in each direction by a stop, the distance of the motion being determined by two regulating screws. As in the receiving relay, the motion in one direction is produced by the attraction of the electro-magnet, and in the opposite direction by the action of a spring, the tension of which is regulated by the screw shown in the lower part of the figure at the right-hand side. The coils of the electro-magnet have a comparatively low resistance, being only about four ohms. As the armature lever is moved to-and-fro under the opposite actions of the electro-magnet and its opposing spring, its lever strikes the two stops, which limit its motion, and produce characteristic sounds which enable the movements to be readily read.

The Western Union Telegraph Company's form of Morse sounder.

FIG. 120.—Morse Telegraphic Recorder.

Morse recording telegraphic instrument.

A Morse recording telegraphic instrument is shown in Fig. 120. The lever L, attached to the armature of a magnet M, is provided at one of its extremities with a stylus or point, that is caused to strike a paper fillet, and mark thereon a series of dots or dashes, according to the length of time that the stylus is kept pressing against the paper fillet. This fillet is maintained in a uniform motion by means of clock-work, shown at W, in the figure. This paper passes between a pair of rollers, *r*, the upper roller being grooved, so that when the lever L presses its stylus against the surface of the paper it

indents or embosses it. As soon as the current ceases to pass through the coils of the electro-magnet, a spring, *n*, withdraws the lever. If now, a person at the other end of the line closes the transmitting key, and instantly releases it, the stylus produces a dot on the paper fillet, since the stylus only touches the paper momentarily. If, however, the operator at the transmitting end keeps his finger on the key for a longer interval, then, during all this time the stylus, being kept against the paper fillet, will mark on its surface a line whose length will depend upon the time that the contact has been maintained. In this way there will be recorded on the paper fillet a series of dots and dashes, that will correspond to the letters of the Morse alphabet.

Action of recording instrument.

Let us now briefly examine the character of this telegraphic code. It is, with some exceptions, the same as that first devised by Morse. This alphabet consists of various groupings of dots and dashes, as represented in Fig. 121. For example, the letter *a* consists of a dot followed by a dash, the letter *n* of a dash followed by a dot, the letter *e* of a single dot, the letter *t* of a single dash, and so on. In sending a message by the Morse alphabet, care is necessary, in order to ensure distinctness, not only in properly spacing the intervals between the separate characters and words, but also in ensuring the proper length of time for the dashes. As a rule, a single dash is equal in length of time to three dots, the space between the separate characters of a single letter is equal to one dot, except in the American Morse, where some of the intervals in *c, o, r, y,* and *z,* are lengthened to two dots. L is produced by a dash that is 1½ times the length of *t*.

The Morse telegraphic code or alphabet.

The American Morse Code or alphabet is employed in Canada as well as in the United States.

American Morse Code

Alphabet

a	· —	n	— ·
b	— · · ·	o	· ·
c	· · ·	p	· · · · ·
d	— · ·	q	· · — ·
e	·	r	· · ·
f	· — ·	s	· · ·
g	— — ·	t	—
h	· · · ·	u	· · —
i	· ·	v	· · · —
j	— · — ·	w	· — —
k	— · —	x	· — · ·
l	——	y	· · · ·
m	— —	z	· · · ·

& · · · ·

Numerals

1	· — — ·	6	· · · · · ·
2	· · — · ·	7	— — · ·
3	· · · — ·	8	— · · · ·
4	· · · · —	9	— · · —
5	— — —	0	——

Punctuation Marks

Period · · — — · · Interrogation — · · — ·

Comma · — · — Exclamation — — — ·

	Printing	Single Needle
1	· — — — —	\\////
2	· · — — —	\\\\///
3	· · · — —	\\\\\\//
4	· · · · —	\\\\\\\\/
5	· · · · ·	\\\\\\\\\\
6	— · · · ·	/\\\\\\\\
7	— — · · ·	//\\\\\\
8	— — — · ·	///\\\\
9	— — — — ·	////\\
10	— — — — —	/////
Period	· · · · · ·	\\\\ \\\\ \\\\
Comma	· — · — · —	\\/\\/\\/
Interrogation	· · — — · ·	\\\\//\\\\
Exclamation	— — · · — —	//\\\\//
Colon	— — — · · ·	///\\\\\\
Semicolon	— · — · — ·	/\\/\\/\\

FIG. 121.—Morse Telegraphic Code or Alphabet. Note the fact that all of these characters consist of various combinations of dots and dashes or dots and intervals.

Various codes were employed in different parts of Europe before it was agreed, at an International European Conference, to adopt a uniform code, now known as the Continental Code. This code is represented in Fig. 122, both for printing or recording, and for the single-needle instrument. A comparison of the Continental Code with the American Code will show that the letters *a, b, d, e, g, h, i, k, m, n, r, t, u, v,* and *w,* are identical in each code. The remaining letters, numerals, and punctuation marks

Continental telegraphic code.

Printing	Single Needle	Printing	Single Needle
a .—	\/	n —.	/\
b —...	/\\\	o ———	///
c —.—.	/\/\	p .——.	\//\
d —..	/\\	q ——.—	//\/
e .	\	r .—.	\/\
f ..—.	\\/\	s ...	\\\
g ——.	//\	t —	/
h	\\\\	u ..—	\\/
i ..	\\	v ...—	\\\/
j .———	\///	w .——	\//
k —.—	/\/	x —..—	/\\/
l .—..	\/\\	y —.——	/\//
m ——	//	z ——..	//\\

FIG. 122.—Continental Telegraphic Code, or the International Telegraphic Code. Note the fact that it is only the spaced characters that differ in the Continental Code from those in the American Morse.

are different. These differences are due to the fact that the Continental Code is employed for use both in the needle instruments and in the sounding apparatus. In the needle systems, the movement of the needle to the left represents a dot, while its movement to the right represents a dash. There is, however, no ready method of representing the spaces. Therefore, the characters of the Morse Code, requiring the use of spaces, must necessarily be represented by different characters.

Another difference between the American Morse and the Continental Code is to be found in the fact that, in the former, there are fewer dashes, and that, consequently, the Morse is a more rapid code than the Continental Code. Taking two equally expert operators, one writing the American Code and the other the Continental Code, the first will be able to send at a rate about five per cent more rapidly than the second. In transcribing, however, it is claimed that a greater number of errors are apt to occur in the American Code, owing to the liability of mistaking the spaced letters for double letters; for example, *o* for *ee*, or *h* for *oo*, etc. Of course this difficulty does not exist in cases where the signals are received by sound, and would, therefore, apply mainly to the case where the single-needle instrument is employed.

Greater rapidity of Morse code.

An expert operator can send in the neighborhood of 40 ordinary English words per minute by employing the Morse Code. For a short time a speed as high as 53 words a minute can be attained. In order to send more rapidly, for such purposes as reports to the newspapers, etc., a system of steno-telegraphy, corresponding to the well-known system of stenography, has been devised by W. P. Phillips. In this system the letters of the Morse alphabet are employed to represent the various sounds, and, in addition, a great number of single letters, double letters, and contractions of words are employed for arbitrarily representing figures, words, and phrases. Of course, in this system, no effort is made to receive the messages by sound, and some form of recording instrument is necessarily employed.

Sending-speed of expert telegrapher.

Steno-telegraphy.

Having now examined the general construction and operation of the telegraphic apparatus employed

in the Morse system of electro-magnetic telegraphy, we are ready to inquire into the differences between the closed-circuited system as employed in America and Canada generally, and the open-circuited system as employed on the Continent of Europe., Difference in American and European telegraphic systems.

The general arrangement of apparatus for the closed-circuited Morse Telegraphic System is represented in Fig. 123. Here apparatus are represented such as will be necessary in four separate stations, of which A and D are the terminal stations, and B and C the intermediate stations. The transmitting keys are represented at K, K, K, K, the relays at R, R, R, R, and sounders, with local bat-

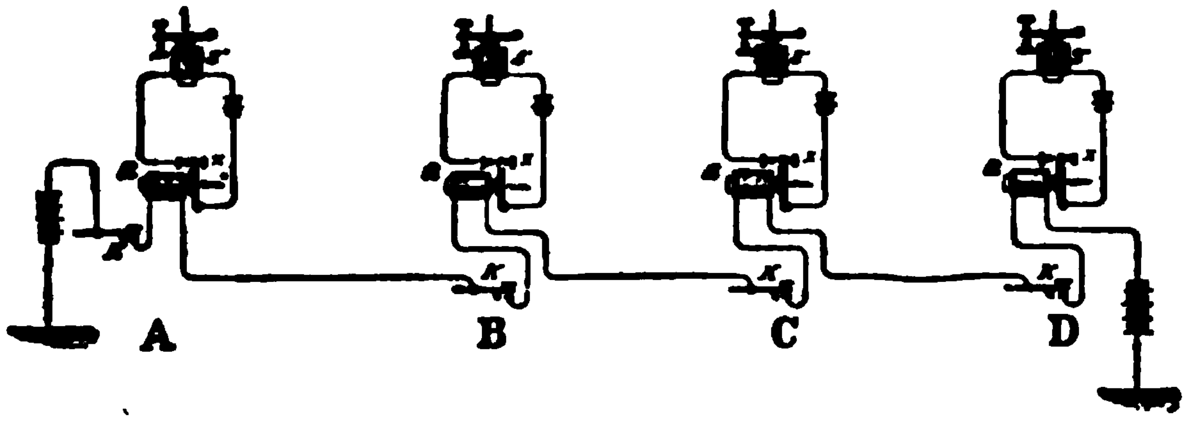


FIG. 123.—The American or Closed-circuited Morse Telegraphic. System.

teries, at S′, S′, S′, S′. A careful examination of this figure will show that only one of the transmitting keys, for example that at A, is opened. Consequently, the entire circuit with all the relays is opened, and their coils, being no longer magnetized, the armatures are resting against their back-stops at x. During this time none of the remaining keys can close the circuit. When the key at A is operated, all the relays throughout the line will be operated simultaneously, by reason of the currents that will be alternately sent into and cut off from their magnetizing coils as the key at A is closed or opened. 'An operating circuit of this character is sometimes called a single circuit, in order to distinguish it from Arrangement of apparatus for the American or closed-circuited Morse telegraphic system.

a multiplex circuit, the arrangement of which will be shortly described. It will be noticed that, in the closed-circuited Morse system, there is a main battery at each end of the line at A and D. In short lines a single battery may be employed at either end of the line, and, in very long lines, a number of batteries may be inserted at some of the intermediate stations.

Method of operation.

In this system, when any station on the line, say C, desires to speak with an operator at another station, say A, the operator at C opens his key, and thus breaks the circuit of all the relays on the line. He then sends over the line A's call, generally consisting of some single letter or combination of letters, thus calling A to his instrument. A now replies, showing that he is ready to receive, and C then sends him the message. Although all the other operators on the line can hear the signals sent, yet they know that the message is for A only. As soon as C is through, he closes the line, thus notifying the other operators that the line is open for their use should they so desire.

Open-circuited system of telegraphy.

In the open-circuited Morse system, as represented in Fig. 124, there are separate batteries employed at each station, as, for example, at *b, b, b,* at the three stations A, B, C, represented in the figure. Here R, R, R, are the receiving relays, and *s, s, s,* sounders, each of which is placed in the circuit of the local battery as represented. A "telltale" galvanometer, G, is placed in the circuit of the main line at each station, to indicate to the operator the condition of his transmitted signals. The transmitting keys are so arranged that, when not in use, the batteries at the station are cut out of the circuit, but all the relays are in circuit. Suppose now that

the operator at any station, say C, desires to send a message to the operator at station A. In order to call the operator at A, C depresses his key, and thus brings its front contact into connection with the battery at *b*. The current from this battery passes over the entire line, and moves the armatures of the relays R, R, at stations B and A, but does not affect his own armature at C, since the depression of the key cuts out its relay. A, hearing his call, replies, and receives whatever message C desires to send.

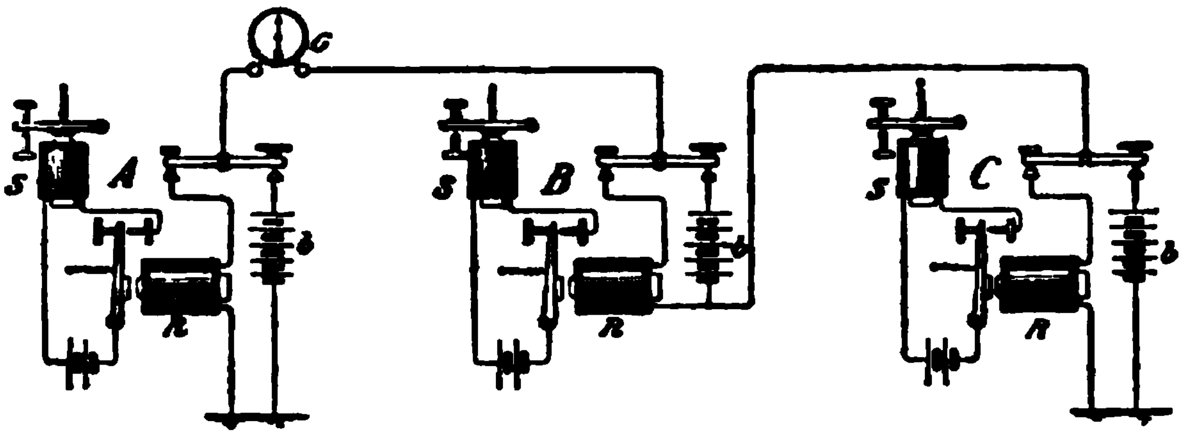


FIG. 124.—The Continental or Open-circuited Morse Telegraphic System.

Some advantages of each of the preceding systems.

While there are advantages in each of these systems, perhaps, the closed-circuited system is preferable, from the ease with which it is possible to introduce additional stations into the line. All that is necessary for this purpose is to cut the line wire and introduce a key and relay, no battery being required. Consequently, for long lines of railroads, the closed-circuited system would appear to be preferable. The open-circuited system possesses the evident advantage of only having the circuit of the battery closed while messages are being sent. This advantage, however, may, perhaps, be more than counterbalanced by the fact that the total battery power required for long lines is greater in the open-circuited system, as well as by the fact that by means of batteries at a few points on long lines, the expense of caring for the same is considerably decreased.

The influence which the establishment of the overland telegraph has had on the civilization of the world is thus referred to by Elisée Reclus, in an article published in 1888 on "The Telegraph the Highest Hope of the Progress of Mankind":

Elisee Reclus on the telegraph.

"Among the material achievements of modern science, that which gives us the highest hope in respect to the future progress of mankind is the electric telegraph. By this invention man ceases to be connected merely with that part of the globe on which he treads so lightly; his liberty is set free from the obstacles imposed by space, and he becomes, as it were, personally present at all the points of space which the conducting wire brings into relation with his thoughts. To the power of his machinery, which might be compared to muscular force, he adds the nervous forces afforded by fibres stretching in every direction; news, transmitted from cell to cell, reaches the brain of man from all the ends of the earth, and his expressed wishes are flashed across continents so as to be transformed into actions on the other side of the globe.

Extent of land lines.

"The construction of electric telegraphs did not commence until about ten years after the completion of the earliest railways; but owing to the comparative simplicity of the world's requisite for the establishment of electric wires, the total length of telegraph wires already much exceeds that of the iron roads. For an expense of about £40,000,000 we have been able to set up more than 1,500,000 miles of wire, a length which would reach nearly 650,000,000 miles if we were to reckon all the double and multiple wires of importance. The new wires unrolled every year would be sufficient completely to girdle the whole circumference of the planet; it is the far-reaching stretch of the human will which

is thus extended so far over the domain which it has made its own by its skill and energy."

The above figures given by M. Reclus refer to the year 1888. Since that time the number of miles of telegraph lines that have been erected in different parts of the world has very greatly increased. According to the Statesman's Year Book for 1902, the total number of miles of overland telegraph wire that has been laid in different parts of the world, excluding Mexico, Chile, Guatemala, Uruguay, Colombia, Peru, and Paraguay, reached the enormous total of 3,591,230 miles. The total number of messages sent during the year 1901 was 425,719,190. To what a great extent has Gray's early hempen cord grown, and how wonderful has been the influence of Morse's first electro-magnetic telegraph!

Present extent of world's telegraph lines.

CHAPTER XVI

LINE CONNECTIONS AND APPARATUS

"Atmospheric electricity is the great enemy of overland lines; and were it not for the protection which the present system of lightning-dischargers in some measure affords, it is probable that repeated sacrifices of apparatus, stations, and even the lives of the employees, would long since have compelled the rejection of the overland system and the adoption of the subterranean and submarine only. The latter are always free from danger, and can receive no injury from atmospheric electricity, so long as they are not in electrical connection with overland lines."—*The Electric Telegraph:* SABINE

TO the overhead telegraph line, lightning flashes were, at one time, a continual menace—both to the lives of the operators and to the apparatus. The long line of bare uninsulated wire succeeded only too well in doing just what Crosse's line, stretched over the tree-tops in England, had done; viz., in drawing lightning from the sky. There was, however, this dfference, that while, in Crosse's case, the lightning flashes were heralded with delight, in the more prosaic case of the overhead telegraph lines they were greatly dreaded. Nor was such dread without reason, since, in the early history of the art, cases are on record where telegraph operators have been killed while at their posts, and this, too, without the notoriety that attended the fatal experiment of Richman in Russia. As a rule, however, the line itself when long generally offers a protection to the operator. It may be interesting, in this connection, to recall some of the dangers to which the early operators on telegraphic lines were thus subjected. The following is quoted from Preece, who recites the observation of M. Breguet:

Dangers of telegraph operators from lightning flashes

"About five o'clock in the afternoon, during a heavy fall of rain, the bells of the electric telegraph at Le Vesitret began to ring, which led the attendant to suppose that he was about to receive a communication. Several letters then made their appearance, but finding they conveyed no meaning, he was about to make the signal "Not understood," when suddenly he heard an explosion similar to a loud pistol-shot, and at the same time a vivid flash of light was seen to run along the conductors placed against the sides of the shed. The conductors were broken into fragments, their edges being fused. The wires of several electro-magnets were also broken; and the attendant, who was holding the handle which moves the needle, sustained all over the body a violent concussion; several workmen standing about him also experienced severe shocks. At the other end of the line, at the Paris station, nothing was broken, and nothing remarkable occurred, excepting that several of the bells were heard to ring."

Breguet on lightning flashes and telegraph lines.

Preece adds to the above the following facts concerning disturbances produced by atmospheric electricity:

"At the Oundle Station of the London and Northwestern Railway, considerable mischief was done in 1846, several of the coils being burst open, and the wires fused; and at the Chatham Station on the Southeastern Railway, a flash of lightning destroyed, in August, 1849, the wire of the bell-coil and both the galvanometer coils. In India, which is occasionally visited with storms of lightning such as we seldom witness in this country, the damage done is often much more severe; and in America the disastrous consequences resulting from the same cause soon after the establishment of the first line of telegraph by Morse, in 1844, rendered it im-

Preece on lightning disturbances on English telegraph lines.

peratively necessary to devise some means for the protection of the wire.

"According to the observations of M. Baumgartner, the direction of the atmospheric electric currents along the telegraph wires is from Vienna to Sommering during the day, and inverse during the night, the change of direction taking place after the rising and setting of the sun. The telegraphic current is less disturbed by irregular atmospheric currents when the air is dry and the sky serene than when the weather is rainy, and the current is more intense with short than with long conductors. When the sky is cloudy and the weather stormy, currents are observed sufficiently intense to affect the telegraphic indicators, and the action is stronger on the approach of a storm."

Some observations in Germany

It will be remembered that experimenters who, in different parts of the world, repeated the classic experiment of Franklin in drawing the lightning from the sky, noted the fact that dangerous discharges could be drawn from their insulated conductors, even when there were no storms. They also noted that exceedingly powerful discharges were obtained during storms when no discharge could be observed to strike the conductor. Discharges of the latter type are due to the inductive action of a neighboring discharge on the insulated wire. It was not possible, therefore, in these early days, for operators to ensure personal safety from lightning even if they abandoned their posts during heavy thunderstorms, since a lightning flash might strike them any time from a clear sky.

Varying conditions of discharge

Since an underground telegraph line, whether subterranean or submarine, is never affected by atmospheric disturbances unless it has some direct

connection with an overhead line, it seemed at first, in the early history of the art of telegraphy, as if all the many advantages which resulted from the use of overhead wires would have to be abandoned, and such lines replaced by underground lines. By properly protecting the overhead wires, however, it soon became possible practically to remove all these difficulties arising from atmospheric electric disturbances, so that, as a rule, neither the operators nor the apparatus are in danger from direct or inductive lightning discharges.

Present comparative safety of telegraphic lines.

The disturbances on telegraph lines due to atmospheric electricity can be divided into two general classes; viz., quiet, continuous discharges, and sudden, momentary, or disruptive discharges. The continuous discharges produce continuous currents that flow in one and the same direction. Such currents are caused as follows: As we have already seen, the atmosphere is almost always in a charged condition. Moreover, the character of this charge rapidly varies from positive to negative. Now, in the case of a long telegraph line, extending for many miles over the country, wherever it happens that the potential of the air is different between different parts of the line, the portions of the line in such districts receive charges from the air, and an electric current is established, which flows through the line from the positive to the negative portion. Or, the passage of a charged cloud over one part of the line may produce a continuous current through the neighboring parts of the telegraph line. While, however, the disturbances produced by such continuous currents are annoying, from interfering with the delicate adjustment of the apparatus, yet, as a rule, the currents are not of sufficient strength to cause any danger either to the operators or to the apparatus.

Two classes of currents produced by atmospheric electricity.

How quiet, continuous currents are produced in telegraph lines.

Auroral telegraphic disturbances.

As is well known, during the prevalence of an aurora borealis, unusual quantities of free electricity exist in the air. During such times, extended overhead telegraph lines frequently collect such quantities of electricity from the air as to render the operation of the line impossible. Reference has already been made to this in speaking of the aurora borealis. Walker, in his "Electric Telegraph Manipulation," refers to such disturbances as follows:

Walker on auroral disturbances on telegraphic lines.

"At such times needles move just as if a good working current were pursuing its ordinary course along the wires. They are deflected this way or that, at times with a quick motion, and changing rapidly from side to side many times in a few seconds; and at other times moving more slowly, and remaining deflected for many minutes, with greater or less intensity, their motions being inconstant and uncertain. These phenomena have occurred less frequently on the part of the line between Reigate and Dover, which runs nearly E. and W., than on the part between London and Reigate, which runs nearly N. and S. When, however, they do make their appearance on the telegraph in those parts, we are prepared to expect auroral manifestations when night arrives, and we are rarely disappointed. The deflections in their variations appear to coincide with the various phases of the aurora. On the branch line running from Ashford to Ramsgate, these deflections have been a much more common occurrence, even when the parts of the line were unaffected, and when no auroral phenomena were noticed. This branch nearly coincides with the curve of *equal dip*."

Disturbances produced by inductive or direct lightning flashes, however, are of a very different character, since, in these cases, the amount of the

charge may be so great as to be exceedingly dangerous. Where wooden poles are employed, in order to permit the highly charged line wire to readily discharge to the ground, the poles every now and then are provided with a wire extending a short distance above the top of the pole, and passing to the ground, care, of course, being taken to so place the lightning-rod that, if accidentally bent, it shall not come in contact with any of the line wires or conductors.

Lightning-rods on wooden telegraph poles.

But some device is necessary in order to protect the operators and the apparatus in the station from the discharge of the line through the station itself. This is accomplished in a variety of ways. It is a fortunate circumstance that a lightning flash consists of a number of separate momentary discharges, that flow alternately in opposite directions. Such alternating currents or discharges find a great impedance offered to their passage by the line wires or conductors, owing to the extremely high inductance possessed by the many turns of fine wire on the receiving relays and other apparatus. So great, indeed, is this impedance that, as we have already seen, a lightning flash will find a smaller resistance in a comparatively short air gap, than it will in the resistance of the coils of wire on the apparatus. Lightning arresters, therefore (of the saw-tooth, or similar type), very much like those used for the protection of telephone lines, may be employed. A well-known form of this type of arrester is shown in Fig. 125, where L_1 and L_2 are respectively the incoming and outgoing line wires. These wires are connected, as shown, through two brass plates, A and C, with the wires *a* and *c*, which enter the station that is to be protected. Both plates of brass, A and C, are provided with saw-shaped teeth, on the

Impedance of telegraph line to lightning discharges.

Saw-tooth lightning arresters for telegraph lines.

edges that face the ground plate B, also furnished with saw teeth. B is connected to the earth by a ground wire, G. Should a lightning flash or non-inductive discharge affect the line, the impedance in the lines *a* and *c*, due to the presence of many turns of insulated wire on the relays or other apparatus, would render it far easier for the discharge to jump across the minute air spaces that exist between the saw teeth intervening between A and B, and the ground plate C, and thus protect the office. In this way, therefore, the discharge never enters the

Action of saw-tooth lightning arrester.

FIG. 125.—Saw-tooth Lightning Arrester. Note the position of the air gaps between the serrated plates.

office, but passes harmlessly to the ground. It will be seen that the form of lightning arrester shown in this figure is practically the same as that explained in connection with the protection of telephone lines from lightning discharges.

Film lightning arrester.

In the film lightning arrester, instead of a film of air being interposed between the line plate and the ground plate, there is a film of some other non-conducting material, such as a sheet of thin paper that has been dipped in paraffine wax. A film lightning

REPEATING, AT MANILA, FIRST CABLEGRAM AROUND THE WORLD

The American Pacific Cable, from San Francisco to Manila, was completed on July 4, 1903, thus filling in the last gap in the direct route of telegraphic communication around the world. The operator shown in the picture is repeating a message sent around the world by President Roosevelt, to his companion, Mr. Clarence Mackey

arrester is represented in Fig. 126, where two separate line wires or conductors, L_1 and L_2, come into the office from the pole lines. Two plates or strips of brass connect with the line wires. On these is placed a thin sheet of paraffine paper, that rests on a ground strip connected with the earth by a wire at G. The sheet of paraffine paper is pressed firmly against these brass strips by a brass screw clamp, C. When a discharge strikes the line wire, the impedance of the line renders it much easier for the discharge to penetrate the paper, and so escape to ground, than to pass through the coils of wire on the instruments. It will be noticed that this form of

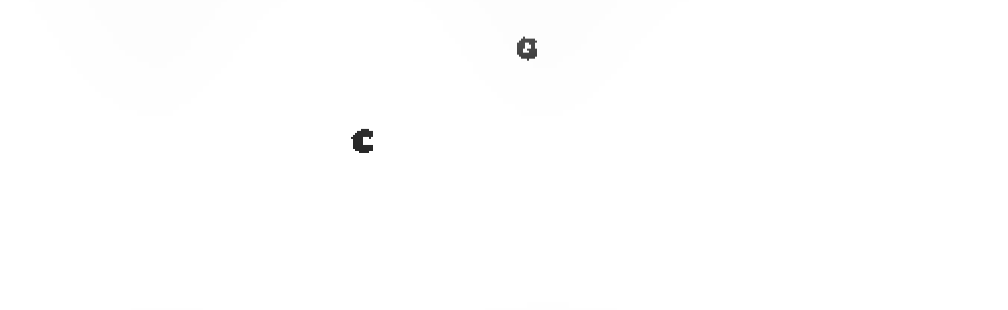


FIG. 126.—Film Lightning Arrester.

film lightning arrester operates on similar principles to the safety film cut-out, employed on series incandescent lamp circuits for the purpose of preventing the extinguishing of a single lamp from throwing the entire series of lamps out of service.

Violent discharges may be less dangerous than slight discharges.

Lightning arresters of the above types depend for their operation on the violence of the lightning discharge, that is, on the great impedance which is presented to a rapidly alternating high-potential discharge. It is a curious fact that when such discharges lack this violence, except, of course, in impulsive rush discharges from which no arrester can ensure protection, they may readily produce more damage in the station, at least so far as the apparatus is concerned, than the more violent dis-

charges. For, whenever the impedance of the line becomes so small from any cause that a part of the discharge can flow through the coils of wire in the station, such currents may readily be of sufficient strength to fuse or otherwise destroy the instruments. Consequently, it is necessary to provide, in connection with the saw-tooth lightning protector, some other form of protector. This is especially the case at the present day, when electric lighting and power circuits are so apt to send dangerous leakage currents into the main telegraph lines. Against such currents the saw-tooth arrester provides no protection. It is now generally the custom, not only in telegraph and telephone lines, but in all lines exposed to lightning discharges, to combine with the saw-tooth protector some form of protector of the class generally known as a sneak-current protector. A common form of such protector consists of the well-known form of safety device called the safety fuse. This, as we have already seen, consists of a thin wire, either of metal or of a metallic alloy, that readily permits the current required for the operation of the line to pass, but which is instantly fused by the passage of a stronger current. Various alloys of lead, German-silver wire, or thin copper wire are employed for this purpose. Since the resistance of a given length of the fuse wire is much higher than the resistance of an equal length of the line wire, it is impossible for a current beyond a certain predetermined strength to pass through the fuse wire. Of course the melting or the blowing of the fuse instantly opens the circuit, so that the line becomes disabled until the break is connected by another fuse.

Why saw-tooth lightning protectors are generally combined with a safety fuse.

Various plans have been devised for readily replacing the fuse wire. In some cases the fuse wire

is supported on a thin sheet of mica, the ends of which are furnished with metallic plates for ready insertion between parallel clips, in the manner shown in Fig. 127. Here the fuse wire is shown on an enlarged scale at the bottom of the figure, in its place between two vertical clips, C, C, at the top of the figure. Such a mica strip, with its fuse wire, is similar to that shown in connection with the carbon block lightning arrester for the telephone.

A method for rapidly replacing a blown fuse wire.

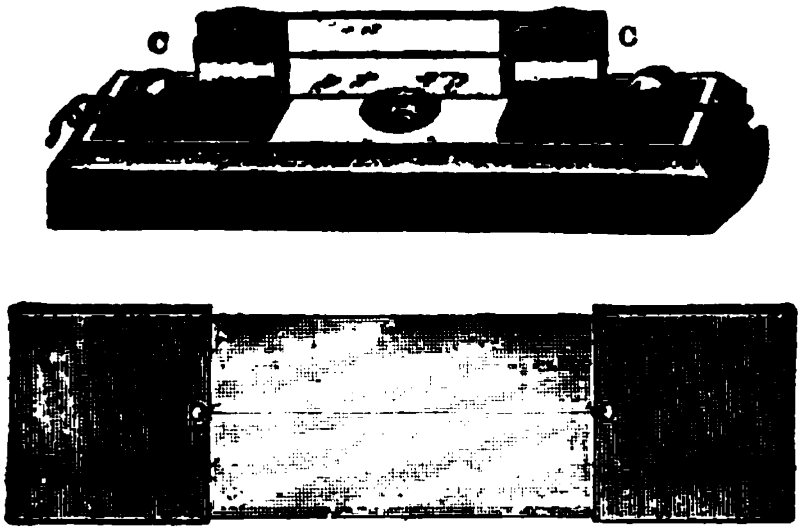


FIG. 127.—Western Union Company's Fuse Wire, showing method for readily inserting same in a circuit.

When the fuse wire is employed in connection with the saw-tooth form of lightning arrester, protection is ensured against both the violent disruptive discharges and the sneak currents, or the quiet discharges. A lightning arrester provided with both these forms of protection is shown in Fig. 128, where the arrester is represented as being placed on a wall outside the telegraph office. The ground plate is connected to earth by the wire T. The line wire L, connected to the plate P, passes thence through *a*, through the fuse wire to *b*, and to the office. Between *a* and *b* is a glass tube, inside of which is a fine iron wire, which is fused should the current become too strong.

Combination of saw-tooth arrester and fuse wire.

Another form of lightning arrester consists in a device by means of which, should the current

strength passing become too great, the circuit of the line wire is automatically opened or broken by the

FIG. 128.—Combination of Saw-tooth and Fuse-wire Lightning Arrester.

Electro-magnetic lightning arrester.

release of a spring device operated by the armature of an electro-magnet. Such an arrester is called an electro-magnetic lightning arrester. In such an arrester an electro-magnet, M, Fig. 129, has its magnetizing coils connected to the circuits of the

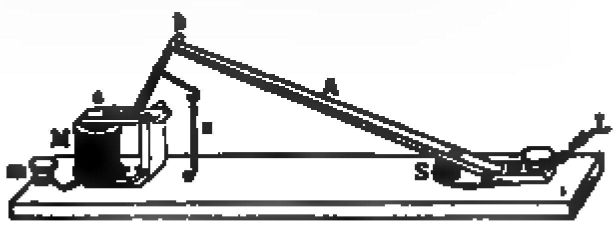


FIG. 129.—Electro-magnetic Lightning Arrester. Note the manner in which the circuit is opened or broken by the action of the armature of M.

instruments to be protected. The line wire, L, is connected to a binding post, *a*. A brass lever, A, is held in the position represented by the lock catch at *h*, against the tension of a spring, S. The coils of the electro-magnet, M, are connected respectively with the metallic catch *h*, and with the instruments

that are to be protected, by means of the binding post *m*. The circuit connections are as follows: From the line wire through A and *h* to the coils of the electro-magnet and the instruments. As long as the current strength which it is designed to maintain on the line in passing through this circuit is not exceeded, the line remains intact, but should the current strength pass the predetermined amount, the attraction of the armature of the electro-magnet, M, releases the lock catch *h*, and the lever A springs back, thus breaking the circuit of the line, and rendering it impossible to maintain an arc.

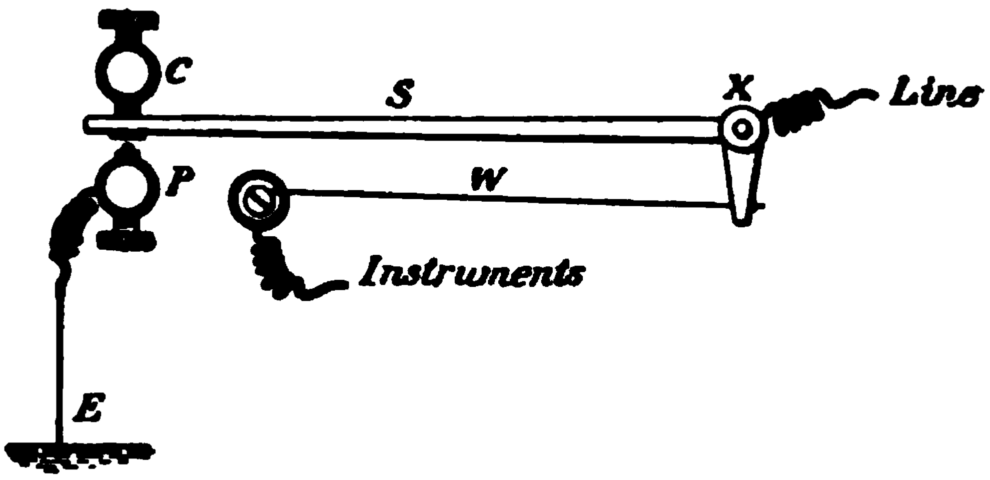


FIG. 130.—The Electro-thermic or Hot-wire Lightning Arrester.

The electro-magnetic form of lightning arrester is objectionable owing to the fact that it tends to break the circuit of the line too frequently, and that, moreover, it does not form an efficient protection against alternating currents. In order to overcome this last objection, the electro-magnetic arrester has been modified in the manner shown in Fig. 130. This operation of the instrument is based on the well-known fact that whether an electric current is of the direct or of the alternating type, it will produce an increase in the temperature of the circuit through which it passes. Here a short wire, W, of high resistance, always in the circuit of the arrester, is connected as shown to the bent lever S, pivoted at X. Under normal conditions, the free

Objections to electro-magnetic lightning arrester.

end of this lever is held against the stop C, a short distance from P, that is connected to the earth at E. The tension of the wire W is such that it is just able to keep S in firm contact with C, against the action of a spring. Should, however, the strength of the current passing through W become too great, the wire expands, and the tension, becoming lessened, permits the lever S to fall into contact with P, and so ground the line.

Electro-thermal lightning arrester.

Where the line wires or conductors enter a telegraph office, they are connected with a piece of apparatus called a switchboard, that corresponds in general to the telephonic switchboard. The object of the telegraphic switchboard is to enable the chief operator to readily change the connection of the line wires and batteries to the different desks, where each operator is provided with his receiving and transmitting instruments. Telegraphic switchboards can be divided into main-office switchboards and way or intermediate-office switchboards. The general principle, however, is the same in each.

The telegraphic switchboard.

The general arrangement of a main office switchboard is represented in Fig. 131. Here a single board or a series of boards is employed, according to the number of separate line wires entering the office, generally placed in a convenient vertical position in the office. On the front face of the board a series of brass bars, 1, 2, 3, 4, 5, 6, etc., called straps, are placed, while on the back of the board a series of horizontal strips of brass, *a, b, c, d, e*, etc., are placed at right angles to the straps. Metallic disks, D, D, D, D, etc., connected with the horizontal strips at the back of the board, pass through holes in the board to its front surface, where they terminate flush with the surfaces of the

Main-office telegraphic switchboard.

straps. These disks are provided with semicircular notches for the insertion of pin or peg plugs. One

FIG. 131.—Main Office Telegraphic Switchboard.
(By permission of William Maver, Jr.)

of these plugs is shown in Fig. 132. It consists of a simple brass plug, provided with an insulating head of hard rubber. The metallic shank of the

Pin or peg plugs.

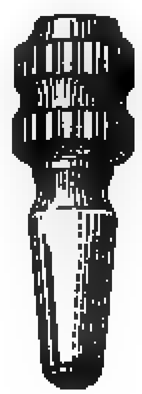


FIG. 132.—Pin Plug of Telegraphic Switchboard. Note the slots in the pin which give it elasticity.

plug is slotted as shown so as to ensure the requisite elasticity. On the insertion of this plug in the various apertures at D, D, Fig. 131, connection is

ensured between the metallic straps and the strips. A board in which the connections are made in this way is generally called a peg switchboard.

Telegraphic spring jacks and peg switchboard.

Spring jacks, somewhat similar in construction to the spring jacks employed in telephone switchboards, are placed at the bottom of the switchboard between each row of vertical straps. Sometimes

FIG. 133.—Western Union Peg Switchboard and Spring-jack Board.

two such spring jacks are placed at the bottom of each of the vertical rows of straps. The general construction of the spring jacks is represented at the top of Fig. 133 with a spring-jack wedge or double-cord plug connected with instruments inserted in a particular spring jack. At the lower part of the same figure is represented a form of the Western Union Telegraph Company's peg switchboard. Here the spring jacks are shown connected with the face of the board below the straps.

Referring now again to Fig. 131, it will be noticed that the main battery, MB and MB′, is divided into two separate sections, with one of the elements or plates, *i.e.*, the positive + or the copper element, connected with the horizontal strip at Pb, and its negative — or zinc element connected with the strip at Pc, the battery being grounded or connected with the earth in the manner shown. If the chief operator should desire to connect the negative end of the main battery to the line conductor, it is only necessary to insert a cord plug, so as to connect any strap with a desk, as, for example, at F,

Operation of telegraphic switchboard.

FIG. 134.—Three-circuit way Telegraphic Switchboard.

as in the figure. Since each wire entering the office is connected with some particular strap, it is clear that, by the removal of the spring-jack wedge from one spring jack to another, any instrument at any desk may be readily placed in connection with the ends of any line wire entering the office, since each desk in the office is connected with a cored plug at the switchboard.

Way-line switchboard.

A way-line switchboard, the name generally applied to the switchboard employed in an intermediate station, is represented in Fig. 134, arranged for three separate lines. The incoming and outgoing lines are connected with the binding screws

shown at the top of the figure, which are connected with the vertical straps. The binding posts at the right-hand side of the figure are connected with the horizontal strips, and with the apparatus in the office. Immediately below the binding posts that are connected with the line wires are placed three lightning arresters. In the switchboard represented in this figure, the pegs are shown as inserted in such positions that the line on the left-hand side of the figure is connected with one of the vertical straps and one of the strips. The second and third lines are also represented as so connected, while the third line on the right is represented as being grounded by the insertion of a peg in the upper right-hand hole.

FIG. 135.—Circular Line-tapping Clamp. Note the ease with which a key and relay are inserted in a break in the main line wire or conductor.

Line-tapping clamp.

Sometimes, during an emergency, such as a collision on a railroad, it is necessary quickly to make a connection with the nearest station, in order to send a call for help. In the American Morse closed-circuited system, this is readily done by merely cutting the telegraph wires and inserting a key and relay in the break. In order readily to make this insertion, a simple device, called a line-tapping clamp, is employed. In the form of clamp represented in Fig. 135, and called from its shape the circular line-tapping clamp, the line wire is inserted

in the slot provided between the two vertical binding posts. When firmly clamped in position, the wire is cut in two by means of a knife or saw. Since the two halves of the circular clamp are insulated from each other, the mere insertion of the relay and key places this improvised station in connection with the line. When the improvised station is no longer required to be employed, a piece of wire is inserted in the cut, so as to complete the line, and the clamp is then left in position until a regular lineman repairs the line at this point.

For convenience in case of emergency stations, a compact form of key and relay are combined in a

FIG. 136.—Combined Telegraphic Relay and Key.

single instrument, which can be made of such small dimensions as will permit it to be readily carried in the breast or hip pocket. Such a piece of apparatus, called a combined pocket relay and switch, is represented in Fig. 136.

Combined pocket relay and key.

There is sometimes a difficulty experienced by operators in readily receiving the message from the sounder, owing either to the noise in a railroad station, or to the fact that the operator is employing the noisy typewriting machine for recording the message. In such cases the expedient is frequently adopted of surrounding the instruments by resounding cases of dry wood, so as to strengthen the sound. Such an instrument is represented in Fig. 137. Here

Adjustable box-sounding instrument

the height of the box sounder is capable of being readily adjusted, said adjustment being necessary not only for the convenience of the operator, but also to avoid disturbances with other operators in the neighborhood of the sounder.

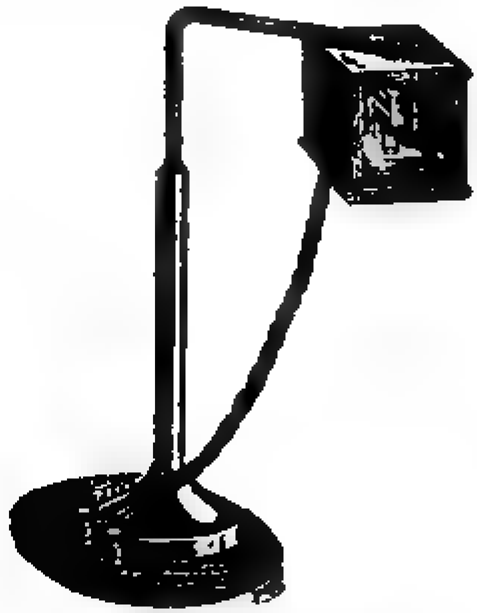


FIG. 137.—Adjustable Box-sounding Receiving Instrument.

Box-sounding relay.

Where the length of the line is not excessive, the sounds produced by the receiving relay are sufficiently loud to permit the operator to dispense with the ordinary sounder, and receive the message di-

FIG. 138.—Box-sounding Telegraphic Relay.

rectly from the relay by sound. Where this is done, it is customary to surround the relay by a case of light wood, so as to increase its sound in a manner

similar to that of the box sounder just described. A form of such a box-sounding relay, employed by the Western Union Telegraph Company, is shown in Fig. 138.

Where recording instruments are employed, as is the case for a variety of purposes in telegraphy, instead of placing the characters received as indented or embossed characters on a paper fillet, as already

Fig. 139.—Ink-recording Register for Morse Characters. Note the general appearance of the characters already marked in ink on the paper ribbon F.

described, some form of ink recorder or register is used. Here the armature lever of the electro-magnet, M, Fig. 139, is provided with a flat sleeve, containing a guide, through which the paper fillet passes just below a disk, D, which is maintained in constant rotation by the same clock-work that moves the paper fillet. R, R′, are two rollers moved by clock-work and employed for moving the paper fillet. The edge of the disk is kept moistened with ink from an

Ink recorder.

ink roller, I. As the armature of the electro-magnet is moved toward and from the magnet poles, the paper fillet is moved alternately upward against the inking disk D, and away from it. The disk D, therefore, will mark dots and dashes on the paper fillet, according to the length of time the disk is kept pressed against it.

Telegraphic repeaters

On long telegraph lines it is necessary automatically to repeat the message sent into the line. This, as we have seen, was done by Morse in his early system of electro-magnetic telegraphy. It is possible satisfactorily to operate telegraph lines without any repeaters for a distance of say 600 miles. Beyond this limit, however, repeaters are advisable. The telegraph line extending from New York City to Galveston, Texas, a distance of some 1,800 miles, is operated by means of three separate repeaters. Lines extending between New York and San Francisco require some six separate repeaters.

Button and automatic repeaters.

In order to be able readily to repeat from one line to another, a class of instruments, called button repeaters, are employed. These devices are operated by hand, and permit messages to be repeated in either direction. In order to avoid the expense of an operator to attend to these repeaters, various forms of automatic repeaters have been devised.

Voltaic batteries.

The electricity required for the operation of an extended system of telegraph lines is obtained either from voltaic batteries or from dynamo-electric machines. Where batteries are employed, there is almost invariably employed some form of Daniell's constant-current battery. Here the form that is practically always used is the modification known as the gravity cell, this form being especially well

adapted for such work. It does not polarize, and, unlike the Daniell cell, it is readily kept in order. This form of cell consists of a plate of copper, C, Fig. 140, placed at the bottom of a glass jar, and provided with an insulated wire passing through the liquid to the outside of the cell. The zinc element consists of a plate of zinc, provided with a number of conical-shaped heads, as represented in the figure at Z, Z. Bluestone gravity cell.

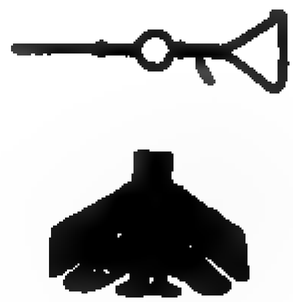


FIG. 140.—Gravity or Bluestone Cell.

The gravity bluestone battery is readily kept in order. When the lighter sulphate of zinc, which floats on the top of the copper sulphate, becomes too concentrated, it is removed by a siphon, the liquid being replaced by water. A small quantity of bluestone is then thrown into the liquid. In large stations a very great number of separate gravity cells are connected together, generally in series-connected batteries, in order to obtain the high E.M.F. required for the proper operation of the lines. In order to prevent the excessive loss of liquid by evaporation, it is customary to place some form of paraffine oil on the surface of the liquid. The use of this oil also serves the purpose of avoiding difficulties which arise from the creeping of the salts; *i.e.*, the climbing of the solution of zinc sulphate over the top of the battery jar, and its subsequent crystallization on the evaporation of the water. The Care of gravity bluestone batteries.

battery is placed where it is easily reached, for example, on an open shelving, as in Fig. 141, where a series-connected battery of 48 bluestone cells is represented.

When the bluestone battery is in good working order, there will be observed a distinct line of demarcation where the colorless solution of sulphate of zinc floats on the top of the denser blue copper

FIG. 141.—Series-connected Bluestone or Gravity Battery of Forty-eight cells, as in a Western Union Telegraph General Station.

sulphate solution. When this line of demarcation is not well marked, and the liquid assumes a dirty appearance, the cell needs refilling. A good bluestone battery should continue to furnish current for a period varying from four to six weeks.

Dynamo-electric machines are now rapidly coming into general use for the purpose of supplying the current employed on telegraph lines. The value of the E.M.F. required will, of course, depend on

the length of the telegraphic line, as well as on the character of the apparatus employed. For example, a single wire between say New York and Boston, 200 miles, might require some 75 separate cells, while one from New York to Buffalo, 430 miles, might require 150 cells, but this only for single or ordinary transmission. In the quadruplex system, where four separate messages are simultaneously transmitted over a single wire, in a manner that we shall shortly describe, the battery power would necessarily be larger in any of the above cases.

Number of voltaic cells required for various telegraphic lines.

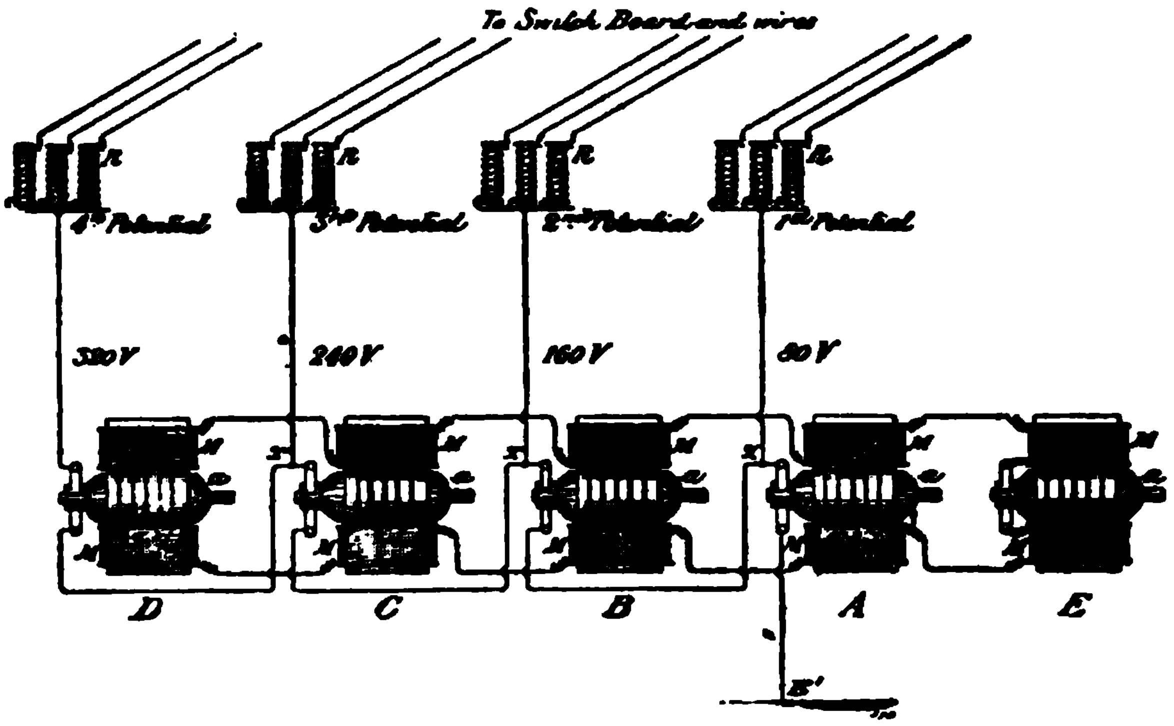


FIG. 142.—Field's Arrangement of Dynamos for Telegraphic Purposes.

In order readily to obtain the various E.M.F.'s required for lines of different lengths, a number of separate dynamos are employed connected in series. Connections are made to the line wires requiring the different potentials from different points of such series-connected dynamos. The arrangement for this purpose, represented in Fig. 142, is that devised by S. D. Field, and is now in use, with some slight changes, in practically all the large offices of the Western Union Telegraph Company. As represented in this figure, separately excited dynamos, of the Siemens-Alteneck type, are employed. The ex-

Use of dynamos in large telegraphic offices.

citer is shown at E, the currents from this machine being sent successively through the field magnets of the separate dynamos A, B, C, and D. Each of these dynamos is wound to produce an E.M.F. of 80 volts. It will be noticed that A, B, C, and D have their armatures connected together in series, so that the voltage produced by A, B, C, and D will be 80, 160, 240, and 320 volts respectively. The circuit of these machines is as follows: from earth at E' to the lower brush of A; from this through the armature of A to its upper brush and to x, where the circuit branches, one branch passing to such line wires as do not require a pressure greater than 80 volts (marked first potential). Here the current passes through resistance coils of German silver wire, by which, within certain limits, the potential can be varied on the lines connected at this point. The other branch of the wire at x passes to the lower brush of the dynamo B, and then through its armature. Since there is thus added to the E.M.F. produced by B an equal E.M.F., the upper brush of this dynamo will deliver a pressure of 160 volts to the branch at x', so that a pressure twice as great will be delivered to the lines marked second potential in the figure. The other branch of x' passes in the same way to the lower brush of C, and then to x'', and the dynamo D, so that the potentials delivered by these last two dynamos will be 240 and 320 volts respectively. Since the machine at A is required to furnish a greater proportion of current than the others, it is wound so as to be able to do this without overheating.

Connections of dynamos in Field's system of telegraphic dynamos.

As we shall see when we describe the operation of the duplex and quadruplex systems of telegraphy, there is needed, for the operation of the apparatus employed in these systems frequent reversals in the

direction of the current sent over the line. Since it is not possible in practice rapidly to reverse the polarity of large dynamo-electric machines which are furnishing E.M.F. for a great number of wires, these reversals in polarity are obtained by operating two series of five dynamos each, one of these series being connected so as to furnish positive polarity, and the other to furnish negative polarity. In order to guard against the failure of either the positive or the negative series, there is provided an additional series of five spare dynamos, so connected with apparatus that they can readily furnish positive or negative polarity should either of the preceding series break down. Such an arrangement is employed in the main Western Union Telegraph office in New York City, this system requiring the employment of fifteen separate dynamos in order to supply the current required on the various lines going out of this great office.

Modification of Field's system of telegraphic dynamos.

In some of the large telegraph offices, dynamos are employed to furnish the current required for the operation of the local circuits. In such cases, the circuits of the sounders are connected in parallel with the circuit of the dynamo, the coils of the sounders being wound for a resistance of about 40 ohms each. Dynamos are also extensively employed in large cities for operating stock tickers and similar instruments.

Besides the employment of dynamos, the storage battery has come into somewhat extended use in telegraph offices. In such cases, a motor dynamo, driven by current taken from the incandescent lamp mains, is employed to produce the current necessary for the charging of the batteries.

Use of the storage battery in telegraph offices.

CHAPTER XVII

HIGH-SPEED TELEGRAPHY

"The instrument that we have principally developed in England is the automatic fast-speed apparatus, based on a principle of preparing messages for transmission by punching, devised by Alexander Bain in 1848."—PREECE

Some requirements of the 20th-century newspaper.

THE high speed at which the most expert operator can send Morse characters over an ordinary telegraph line is far too slow to meet the requirements of the 20th century newspaper, which must have the latest news in its edition, even if only received in a distant city at a comparatively short time before going to press. For such purposes, a much higher rate of speed is necessary than it is possible to acquire by hand. Various plans have been devised for such high-speed transmission. They all, however, consist practically in methods whereby the message can be sent by machine transmission instead of by hand transmission. Before the advent of the system of wireless telegraphy, a transatlantic steamer, which was bringing over an important piece of news obtained from a passing vessel, might readily have prepared on shipboard, on a fillet of paper, news intended for the Associated Press. Immediately on its arrival, the paper fillet could be sent by special messenger to the Associated Press, which, if the news is considered sufficiently important, wires the newspapers in distant cities to hold their latest edition open for a short time. The messages prepared on the paper fillets are then rapidly transmitted by suitable apparatus to

How the news can be rapidly transmitted far and wide over the continent.

different cities of the country, so that, within a comparatively short time after the arrival of the steamer, the matter has been set up, transferred to the pages of the papers, and is rapidly being printed for their next edition. Of course, at the present time, much of this would be discounted by systems of wireless telegraphy.

In the ordinary Morse system of telegraphic transmission, the message, as we have seen, is sent into the line by a series of makes-and-breaks in the circuit. For example, to send a dot followed by a dash, the transmitting key is first depressed for a moment, released, and again depressed; to send the dash the key is kept depressed for a longer time. For the first signal, consequently, there will be printed at the receiving or recording apparatus, or embossed or indented, a dot, while the second signal will be recorded as a dash. In long lines a different method is generally adopted. A form of transmitting key, called a double-current key, is employed. This key is so arranged as completely to reverse the battery after each signal. In such a case, therefore, instead of the signals being formed by breaks in the circuit, a reverse current is sent into the line after each signal, the battery, when working, being always connected to the line alternately in one direction or the other, that is, positive and negative currents being alternately sent into the line. The key employed for this purpose is called the double-current key, and the method itself is called the double-current method, in order to distinguish it from the regular Morse method, or, as it is sometimes called, the single-current method. Or, to put the same thing in a somewhat different way, in the ordinary Morse system the spaces between the separate characters are made by breaking the circuit of the line. In the

Single-current transmission.

Double-current transmission.

double-current system, the spaces are obtained by applying that pole of the battery to the line which will cause the withdrawal of the armature of the relay from its local contact point. In such cases, a form of relay called a polarized relay must be employed, similar to that already described in connection with the magneto-call apparatus employed on telegraph lines.

Polarized relay.

Now, in any system of machine telegraphy, or, as it is sometimes also called, high-speed or automatic telegraphy, the message which it is desired rapidly to transmit is prepared by perforating a fillet of paper with a series of holes. This paper fillet, when rapidly passed through the proper transmitting instrument, sends into the line the necessary electric impulses at a far higher rate of speed than could possibly be done by the most expert operator.

The perforated paper fillet for automatic transmission.

The double-current method of signalling is generally employed in high-speed telegraphy, since a much higher rate of transmission can be obtained with this system than with the ordinary Morse single-current system. Whenever an attempt is made to transmit signals very rapidly over a telegraphic line, and to record the same either by any system of embossing or by an inking or chemical recorder, there is a tendency for the recorded signals to run together, that is, for the separate signals to increase in length, so that, instead of being received as clear dots and dashes, they are run together, sometimes to the extent of making a continuous marking on the record ribbon. These prolongations are known technically as "tailings," and are due to the fact that the line wire has not had sufficient time in which to clear itself of the charge produced by the preceding signal. These tailings will necessarily vary consid-

"Tailings" in received Morse characters.

erably with the length of the line wire, and with its electro-static capacity. Now, when there is transmitted into the line currents of opposite polarity for each alternate signal sent into the line, as is done in the double-current system, the opposite charge sent into the line neutralizes or wipes out the previous charge, and thus decreases the tendency to tailings.

The perforations of the paper fillet are effected in a variety of ways. In the single-current method of transmission, where only a single row of perforations is required, consisting of a series of long and short holes or perforations corresponding to the dots and dashes of the Morse characters, the matter is a comparatively simple one. The separate characters forming any single letter can be punched either successively or, as is generally done when high speed is required, by a single depression of the key of the transmitting apparatus. There is frequently employed for this purpose an apparatus consisting practically of a typewriter, by the depression of the keys of which the Morse characters required for any message are impressed as perforations on the paper fillet. In the double-current method of signalling, however, where a double row of characters is necessary, although apparatus has been devised to make these characters by a single depression of the perforating key, yet, in such cases, it is necessarily more or less complicated, and, therefore, apt to get out of order, so that punching apparatus of the single character is generally employed.

How the paper fillet is perforated.

In order to transmit the message the perforated fillet is passed over the surface of a metallic cylinder connected with one pole of a battery, while one or two metallic points, connected with the other pole of the battery, are permitted to rest on the surface of

How the perforated fillet transmits.

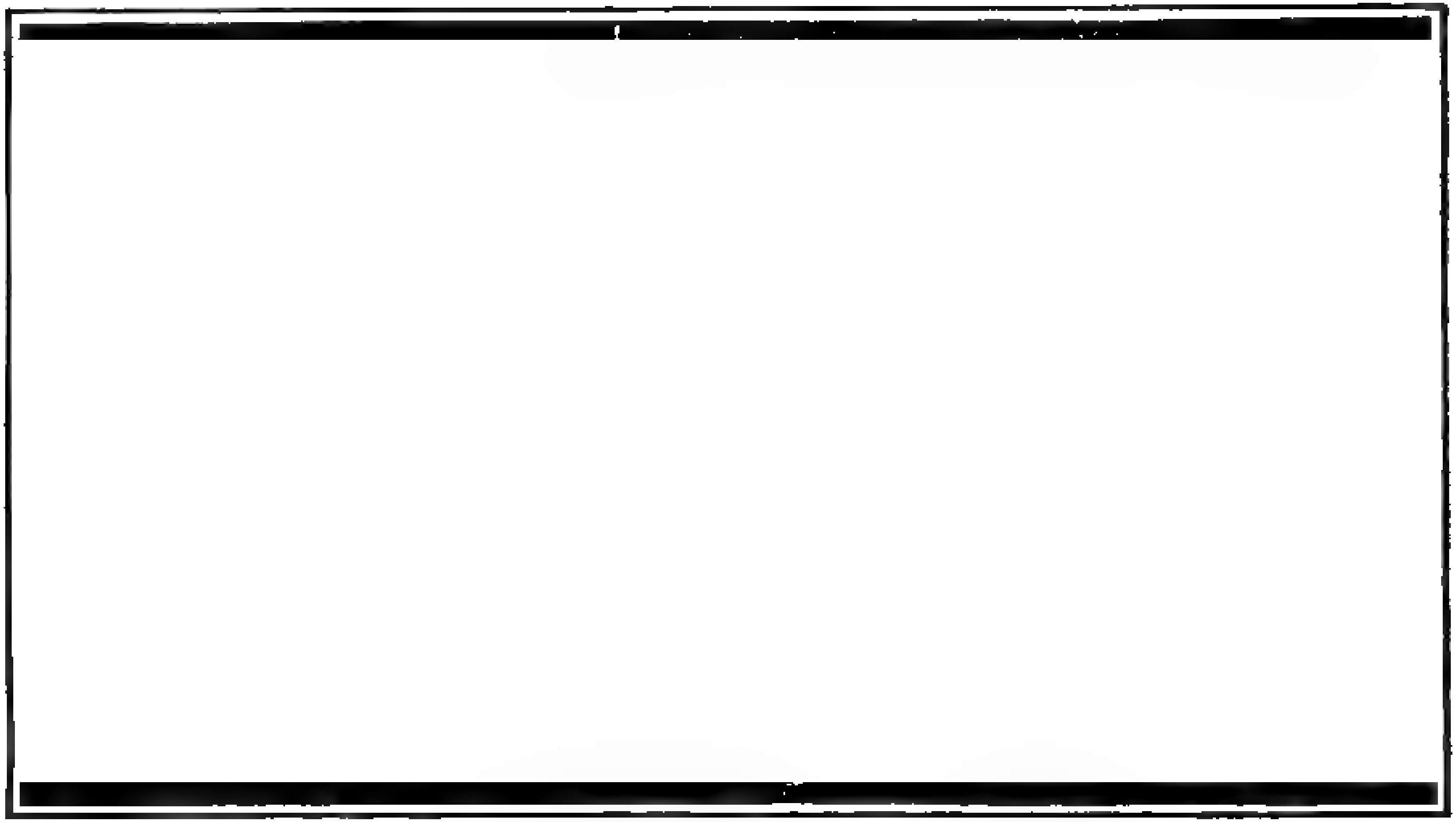
the paper fillet. As this is moved rapidly by machinery under the pen, whenever the perforations come under the pen the points make contact with the metallic cylinder below, and thus transmit electric impulses over the line.

Wheatstone's perforating apparatus.

A form of perforator, suitable for the double-current transmission and employed in the Wheatstone automatic telegraphic apparatus, is represented in Fig. 143. Here the perforating apparatus is operated by the depression of three keys, A, B, and C, provided respectively for producing perforations cor-

FIG. 143.—Perforator for Automatic or Machine Telegraphy. Note the three separate rows of perforations in the paper fillet DD.

responding to dots, spaces, and dashes. The paper fillet D D is driven by means of clock-work from right to left, some characters having already been punched in the fillet. It will be noticed that these perforations are arranged in three separate rows, the central line being employed for the purpose of guiding the band of paper both through the perforating and the transmitting machines. The outside perforations determine the dots and the dashes, a dot being obtained by a pair of opposite holes in the same vertical line, while a dash is obtained by a pair of holes in diagonal outside lines.



WIRELESS TELEGRAPHY AT SEA

In the picture a Marconi operator on the S.S. "Philadelphia" is at work with his instruments. The transmitter key is seen under his hand and the induction coil to the right

A Wheatstone transmitter is represented in Fig. 144. The perforated paper fillet, wound on a reel, R, is placed as shown under a roller driven by clock-work, this clock-work being moved by means of weights hung on chains, shown at K. As the paper fillet is rapidly moved, a pair of needle points, connected with one of the poles of a battery, and placed underneath the paper fillet, are maintained in a constant to-and-fro movement by the action of the clock-work. Wherever there are perforations in the paper, these needles make contact with a metallic piece that is connected with the other pole of the

Wheatstone's transmitter for high-speed telegraphy.

FIG. 144.—Wheatstone's Transmitter for Automatic or High-speed Telegraphy.

battery, and thus transmit impulses that correspond with the characteristic perforations that are placed on the paper. It has been found possible, in actual practice, to transmit by this instrument as rapidly as 400 words per minute. It has a device for regulating the speed at which the paper fillet is moved.

The arrangement of the Wheatstone receiver is shown in Fig. 145. This instrument is an ink recorder. The electric impulses sent over the line are received by a polarized relay of great sensitiveness. The movements of this relay control a local circuit,

Wheatstone's receiver for high-speed telegraphy.

which operates an electro-magnet, the movements of whose armature cause the paper fillet D D, driven by clock-work operated by weights hung to the chains W, to be moved toward or from an inked wheel.

Where a higher speed of receiving is necessary, the electro-magnet of the receiving apparatus is replaced by some form of chemical receiver, since neither the changes in the direction of a moving mass of material nor the changes in the polarity of magnetism can equal the speed with which a chemical

FIG. 145.—Wheatstone's Receiver for Automatic or High-speed Telegraphy.

Electro-chemical receiver.

receiver is able to act. The operation of the chemical receiver is based on the well-known fact, that when a current is sent through a fillet of paper moistened with various chemical substances, an electrolytic decomposition is effected, which results in a permanent mark being impressed on the paper. One way of obtaining such mark is based on the well-known property of iodine to produce a clear blue color in a solution of starch. For this purpose a solution of potassium iodide is dissolved in starch water.

The following proportions are suitable for the preparation of iodine-starch printing paper; viz., one part of potassium iodide, 20 parts of starch paste, and 40 parts of water. A platinum point is employed in connection with this solution. Another solution frequently employed consists of the following: 5 parts of yellow prussiate of potash and 150 parts of ammonium nitrate. The use of the ammonium nitrate is for the purpose of keeping the paper moistened during all conditions of the weather. This is done by reason of its attraction for the moisture of the air, the nitrate of potash being a well-known hygroscopic substance. In this case the dots and dashes are marked on the paper fillet in the well-known Prussian blue, a ferro-cyanide of iron, the iron being dissolved during the electrolysis from the steel or iron pen employed in the receiving instrument.

Formulæ for electro-chemical printing papers.

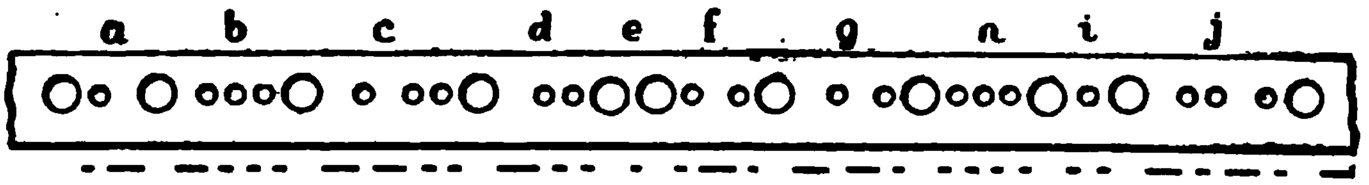


FIG. 146.—Perforations Employed in the Anderson Chemical System of Automatic Telegraphy. Note the fact that it is the blank spaces between the perforations that produce the dots and dashes, and not the perforations.

The transmitter and chemical receiver invented by Frank Anderson operates on principles different from those just described. Here a single row of perforations is employed, as is represented on a paper fillet containing the characters of the Morse alphabet from *a* to *j*, inclusive, Fig. 146. It will be observed that, in this system of transmission, it is the blank spaces between the perforations that produce dots and dashes, and not the perforations themselves; for instance, in order to produce the letter *a*, the dot and dash required are produced by a short space between a large hole and a small hole, while

The Anderson chemical system of automatic telegraphy.

the dash is obtained by a greater length or space left between a small and a large hole. Again the two dots required to produce the letter *i* are similarly obtained by two small spaces lying on either side of a small hole placed midway between two large holes. This difference is rendered necessary by the fact that in the Anderson system it is only while the transmitting contact pin passes over the uncut parts of the paper that the electric currents are able to pass into the line.

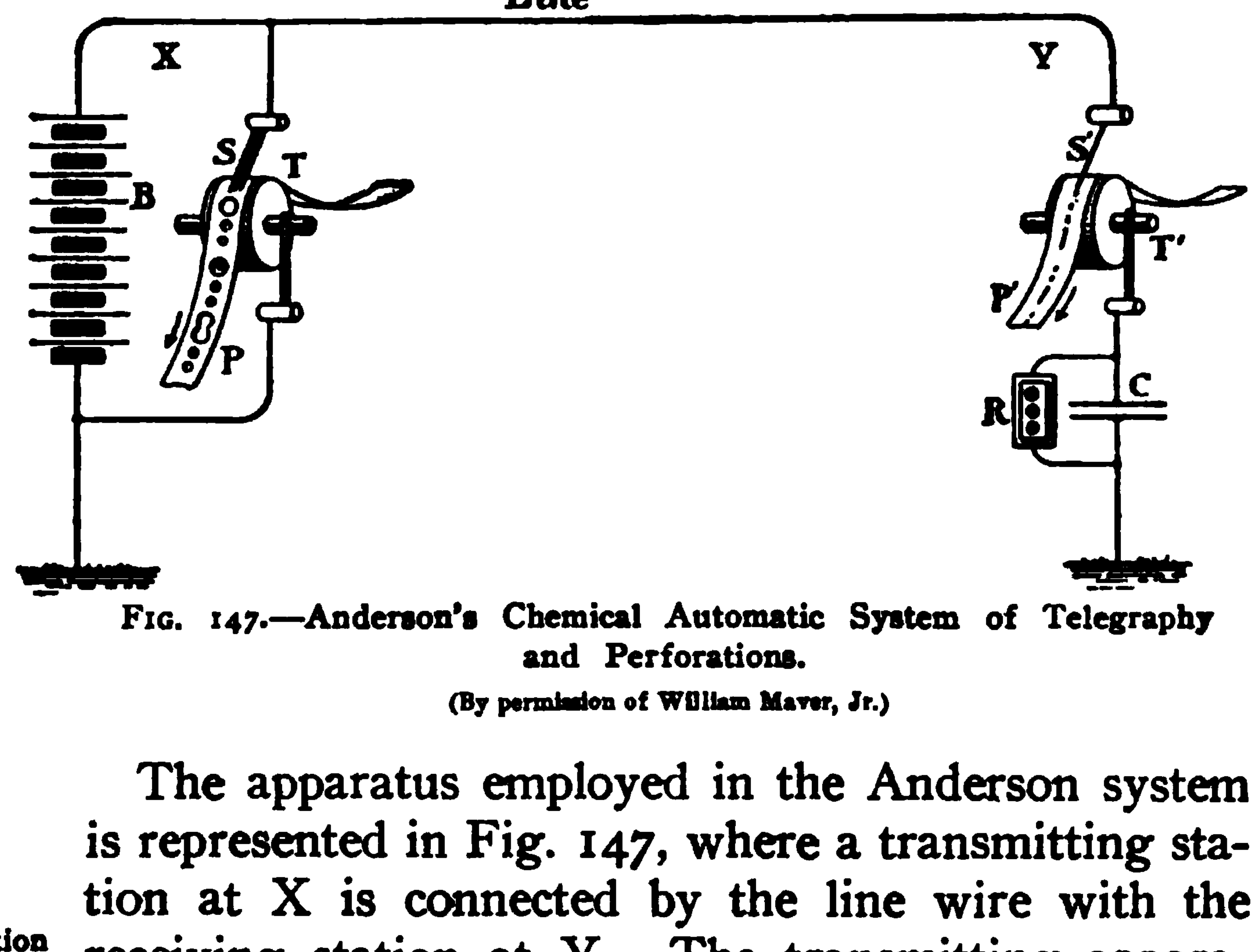


FIG. 147.—Anderson's Chemical Automatic System of Telegraphy and Perforations.

(By permission of William Maver, Jr.)

The apparatus employed in the Anderson system is represented in Fig. 147, where a transmitting station at X is connected by the line wire with the receiving station at Y. The transmitting apparatus consists of a pen, S, provided with metallic fingers, that rest upon the surface of the fillet of perforated paper, P. This paper is placed on the surface of a metallic cylinder, T, that is put in the circuit of the battery, B, the pen, S, being connected to the same battery and to the line, in the manner shown. On the paper fillet being driven by means of clock-work in the direction indicated by the arrow, as the perforations come opposite the

Operation of the transmitter.

pen S, the points come in contact with the metallic cylinder, so that the battery is short-circuited, and a drop of potential occurs on the circuit of the line wire connected with the receiving station at Y.

In order to permit the single row of perforations on the transmitting paper fillet to employ the double-current system of transmission necessary in all systems of rapid machine telegraphy, the inventor has adopted the ingenious expedient for obtaining the equivalent of this double current by the use of a condenser at C, placed in the circuit of a variable resistance, R, between the ground and the receiving instrument. From the connection of the pen S, with the circuit of the battery and the line at X, it will be seen that the battery, B, is in full connection with the line wire when the pen is in contact with the unperforated portions of the paper fillet. During these times, therefore, the current is sent into the line wire, and passing through the receiving paper fillet P′, decomposes the solution of chemical salt with which the paper is moistened, and marks on its surface the impulses sent over the line with the full force of the battery B. During such times, too, the condenser at C will be charged with a certain polarity, the amount of which will depend on the value of the resistance inserted at R. When, however, the transmitting pen S falls into a hole in the paper, and the potential of the line wire falls practically to zero, the condenser C immediately parts with a portion of its charge, and produces a current in the opposite direction to that sent through the line when the transmitting instrument had been resting on the uncut portions of the paper, thus interrupting the flow of the marking current through the paper. There is, therefore, obtained in this manner the equivalent of the double or reverse current em-

Operation of the receiving instrument.

The use of the condenser.

ployed in systems of double-current transmission. Besides the wiping out, or clearing, of the wires from the effects of the marking charge thus effected by the reverse current received from the condenser C, the fact that, at such moments, the line is short-circuited through the ground, provides in a very efficient manner for the static discharge of the line through the earth. In this manner only a small portion of the charge remains in the line to be neutralized by the reverse current from the condenser C.

But even the rate at which any of the systems above described are capable of transmitting, say 400 words per minute, is not sufficient to meet the wants of the present age. Attempts have, therefore, been made to increase this speed. Now, in any case, the speed of transmission will vary greatly, according to the conducting power and other qualities of the line employed. Where very heavy copper conductors are used, so that the conducting power of the line is high, the speed of transmission can be markedly increased. In this manner, as well as by greatly improving the details of receiving and transmitting instruments, P. B. Delany has rendered it possible to largely increase the rate of transmission by his system of machine telegraphy. By this system, he is able to increase the carrying capacity of a single wire so as to make it equal to that of 80 wires operated by ordinary Morse, or that of 25 wires operated by quadruplex Morse. In the Delany system, as in other systems already described, the message which is first punched in the paper fillet is transmitted by a machine transmitter at a rate varying from 1,000 to 3,000 words per minute.

Delany's system of machine telegraphy.

The Delany method of machine telegraphy employs the double-current system of transmission, and

receives by means of a chemical receiver. The dots and dashes are transmitted by means of two separate rows of small holes on a fillet of paper. One of these lines corresponds to the dots and the other to the dashes of the Morse Continental Code, no spaced letters being employed. The transmitting instrument is represented in Fig. 148, where the perforated fillet is placed between two rollers, R, R, through which it is driven at a rapid rate by means of suitable clock-work. Two pairs of metallic brushes, *aa′* and *bb′*, connect respectively to the opposite poles of a split battery, EE′; *i.e.*, a voltaic

Delany transmitter.

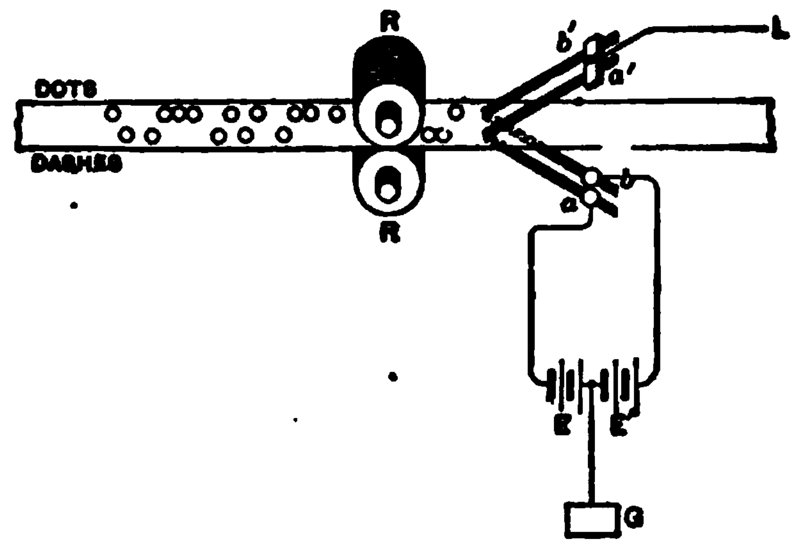


FIG. 148.—Delany's Transmitter for Machine Telegraphy. Note the separate lines of dots and dashes as perforations on the paper fillet.

battery that is grounded at its middle point. These pairs of brushes are employed for transmitting currents of electricity of opposite polarity. Wherever it happens that the brushes in contact with the perforated paper fall through a dot hole, a positive current of brief duration is sent through the line wire, but where a dash hole exists, the *aa′* brush comes into contact, so that a negative current is transmitted.

In the receiving instrument the characters transmitted are received on a paper fillet, moistened with a solution of yellow prussiate of potash. Three

iron needles are employed. The central needle is connected with the ground at E, Fig. 149, while the two outside needles are connected with the line wire L. As the band of paper is moved rapidly under these points, whenever a positive current is received, *i.e.*, when such current passes from the line to the ground, these needles deliver jointly their current through the paper to the metallic plate on which the paper rests, whence the current passes back through the middle needle to the ground at E. This causes a dot to be produced under each of the two outside needles. When, however, a negative current is received, *i.e.*, when a current passes from the ground to the line, such current passes through the central

Receiving instrument for Delany's high-speed telegraphy.

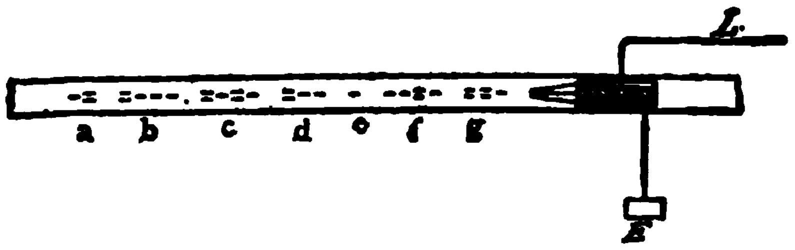


FIG. 149.—Delany's Electro-Chemical Receiver for Machine Telegraphy.

needle and through the paper to the plate below, and from this point is divided into two branches, so that a dot will form beneath the central needle.

Since the rate of transmission by machine telegraphy greatly exceeds the maximum rate of transmission by the telephone, and since, moreover, in the system of machine transmission there is left a permanent record of the messages sent, which is not the case with the telephone, it has been hoped by inventors that, through improvements in the rate of transmission, the telegraph will be able eventually to take the place of the mail for important business correspondence, and this not only without loss in the accuracy of the correspondence, but also with a great gain in the time required for its transmission. It will readily be seen that, in any system of machine

The telegraph *vs.* the mail for business correspondence.

telegraphy, it would be practically impossible to tap the telegraph line, and so obtain surreptitious information, unless one went to the great expense of providing the receiving instrument for the recording of the message. There would, therefore, be added to such a system of rapid telegraphic correspondence the great advantage of absolute secrecy.

Absolute secrecy.

The average business letter will probably not exceed 100 words. The average cost of transmission is in the neighborhood of 30 cents. Now suppose that, by reason of more rapid transmission, and, consequently, of a greatly increased extent of business, it would be possible for the telegraph companies to cut the cost of a telegram in half, while, at the same time, they would permit the number of words transmitted for a single charge to be doubled. Then it would be possible to telegraph important letters between two cities, say between Chicago and New York, for 20 cents for 100 words, and between New York and Boston, Baltimore or Washington, say for 15 cents. Such rates could probably be charged profitably by all great telegraph companies, provided a sufficient increase in business was obtained. If matters can ever be so arranged that the telegraph is able to compete in actual cost of transmission with the mail, there can be no doubt as to the enormous increase in the amount of telegraphic correspondence by reason of the great benefit bestowed on business men. It is to be hoped that such a state of affairs may be rapidly brought about.

C. L. Buckingham, of New York City, has a somewhat similar system of machine telegraph. This system has been operated commercially over the Western Union Telegraph Company's circuit and over one-and-a-half million messages have been

Buckingham's system of machine telegraphy.

successfully transmitted by it. A record has been attained of 2,429 words transmitted between New York City and Chicago in 23 minutes and 24 seconds. In this system the messages are received, not in Morse characters on a paper fillet, but in typewritten words on message blanks, which are, therefore, then ready for instant delivery.

The messages received typewritten

CHAPTER XVIII

DUPLEX, DIPLEX, QUADRUPLEX, AND MULTIPLEX TELEGRAPHY

"The invention all admired, and each how he
To be the inventor missed; so easy it seemed,
Once found."—*Paradise Lost:* MILTON

WE have thus far considered only the case of single transmission over a telegraph line, that is, when one telegraph line or wire is having a message transmitted from either of its ends the wire can not be employed for any other purpose. We will now consider the case where it is possible simultaneously to transmit two, four, or a greater number of messages over the same line wire or conductor, under such circumstances that half of these messages are being sent in one direction, while the remaining half are being simultaneously sent in the opposite direction.

How the capacity of a telegraph line may be increased.

Duplex telegraphy.

Duplex telegraphy consists of a method by which two separate messages can be simultaneously transmitted over a single wire in opposite directions. The first proposition to accomplish this was made by Moses Farmer, in 1852. Gintl, Director of the State Telegraph of Amsterdam, invented a practical system of duplex telegraphy in 1853, and had this system in operation, in connection with a chemical receiver, on a line between Vienna and a neighboring town in 1854. Preece, in England, in 1855, Siemens & Halske, in Germany, in 1855, and Farmer, in 1858, also introduced improved apparatus,

Some early history.

but none of these systems came into extended use. Stearns, of Boston, in 1858, and subsequently Edison and others, greatly extended and improved the system, so that there was finally evolved, as a result of the labors of all these inventors, a system of duplex telegraphy that has reached such a state of efficiency that practically all important lines, even including cable lines, are now operated on the duplex system. In a duplex system, since either end of the line is able to send at the same time, there must be two operators at each end of the line, one to transmit and the other to receive. In other words, a single-line wire, operated on the duplex system, can give employment to four separate operators.

Differential system of duplex telegraphy.

There are two distinct methods whereby a telegraph line may be duplexed; viz., by what is called the differential method, and by what is called the bridge method. In the differential method, the transmitting and receiving instruments may either be electro-magnets, operated by the movements of their armatures, or coils of wire intended for the operation of magnetic needles. The coils of these instruments are wound with two separate circuits, in such a manner that the polarity produced by the current passing through one of the coils is opposite to the polarity produced by the current passing through the other coil. When, therefore, two equal currents pass through these coils, there is no magnetic action produced, so that, in the case of the electro-magnet, its armature is not attracted, or, in the case of the needle instrument, the needle is not deflected. Coils wound in this manner are said to be differentially wound.

Differentially wound coils.

In the differential system of duplex telegraphy, represented in Fig. 150, the receiving and trans-

mitting instruments at A and B are differentially wound, one of the coils of A being connected to that of B, through the line wires *b*, *b′*, as shown, while the other is connected to the rheostats at R and R′. The battery at A has its copper pole, C, connected to the ground, while that at B has its zinc pole connected to the ground. If, therefore, the keys at both A and B are depressed at the same time, the currents that they send into the line will strengthen each other. If, however, only the key at A be depressed, the current will branch at *e*, and, care having been taken to have the resistance of the circuit *e a b b′a′e′r′* equal to the resistance of the circuit

Action of the differential duplex system.

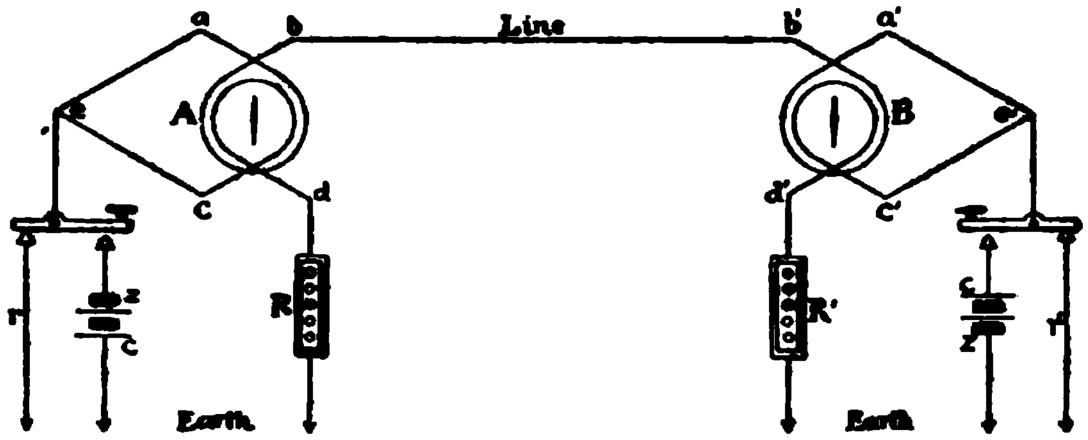


FIG. 150.—Differential Method of Duplex Telegraphy. Note the differential winding of the coils A and B.

e c d R, the current divides equally between the differentially wound coils on the instrument at A. Consequently, there is no deflection of its needle. At the station, B, however, this current can only pass through one of the windings at B. Consequently, it deflects the needle, and so makes a signal at this station.

If the keys at A and B are simultaneously closed, the effect produced on the line is to add the currents of the two batteries; but each rheostat circuit is traversed by its own battery current only. The line-connected coils of the receiving instrument, therefore, will have stronger currents flowing through

Currents not sent in opposite directions.

them, so that the needles of both will move. Each sender's instrument is unaffected by the current he sends into the line, and is, therefore, ready to be operated by the currents sent into the line from the other end. Two currents, therefore, do not pass each other in duplex telegraphy. On the contrary, they are sent into the line in the same direction.

Action of condensers sometimes necessary.

Since, when either key is sending impulses into the line, there is necessarily some interval of time during which the circuit of the line will be broken for incoming currents, the transmitting keys are arranged so that they close the second contact before breaking the first contact. Small resistances are introduced between the back stops of the keys and the earth, in order not to destroy the balance on the introduction of the resistances of the batteries at A and B. Rheostats are inserted at R and R′, in order to maintain the balance in the resistance of the circuit, since, otherwise, the current would not divide equally at the points *e* or *e′*, and thus flow equally through the two halves of the differentially wound coils on the instruments. Wherever the length of the line to be duplexed exceeds 100 miles or so, or where a great proportion of underground cable is employed, it is necessary to introduce condensers into the circuit, so as to balance the line as regards its electro-static capacity.

Want of space prevents us from discussing the bridge method of duplexing a telegraph line.

Diplex telegraphy.

In diplex telegraphy, two separate messages can be simultaneously transmitted over a single line wire in the same direction. In order to be able to do this, it is necessary that two different transmitting keys be provided, by the movement of one of which the

direction of the current through the line may be changed, and by the movement of the other the intensity of the current transmitted through the line may be changed, so that one of the messages is sent over the line by changes in the direction of the current, and the other message by changes in the intensity of the current.

Action of the two transmitting keys in diplex telegraphy. The apparatus required for a system of diplex telegraphy is represented in Fig. 151, where the station A is provided with the two keys before referred to, key K_2 being arranged to reverse the direction of the current, and key K_1 to vary the strength of the current. An examination of this figure will show that when key K_2 is at rest, one pole of the

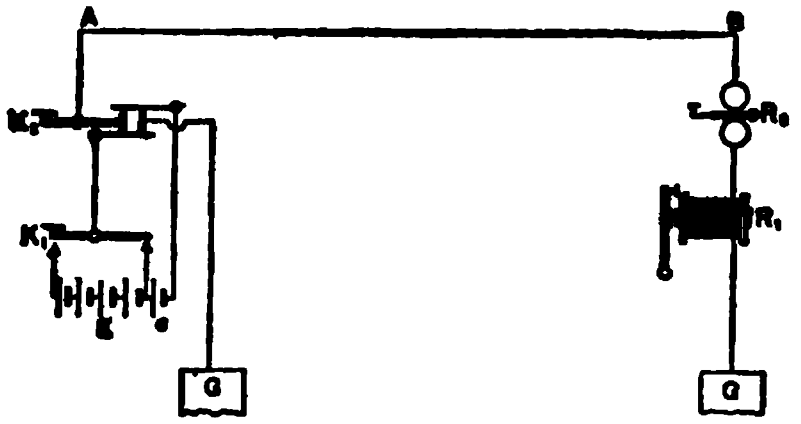


FIG. 151.—Diplex Telegraphy. Note the means adopted for varying the direction and for varying the strength of the current.

battery is connected to the line, and that when it is depressed, the other pole of the battery is connected to the line, so that its movements will reverse the direction of the current. Key K_1, on the other hand, when at rest has a small E.M.F. connected to the line, and when depressed has a stronger E.M.F. so connected. Its movements will, therefore, send variations of strength of current into the line.

Action of receiving instruments At the receiving end of the line there are two relays, R_2 and R_1. R_2 is a polarized relay, so arranged that it will respond to negative currents and not to

positive currents, while the relay R_1 is an ordinary non-polarized relay, so adjusted that it will not respond to the feeble current from the feeble E.M.F., but will readily respond to the stronger current. In other words, the relay R_2 will respond to key K_2, and not to key K_1, while the relay R_1 will respond to key K_1, and not to key K_2. It is evident, therefore, that by such means it will be possible to transmit two messages over the same line wire in the same direction.

Quadruplex telegraphy.

Now, without going into the subject of quadruplex telegraphy at any length, it will suffice to say that when a single line wire is provided with a suitable diplex system at each end, and a proper adjustment for balance is made, it will be possible simultaneously to transmit two messages from each end of the line, or, in other words, that such a line may be quadruplexed. A quadruplexed line would require for its proper working four operators at each end of the line, two to transmit and two to receive, or eight operators in all.

Multiplex telegraphy.

There are a variety of different ways in which multiplex telegraphy can be obtained. In the harmonic system of Gray, this is accomplished by the transmission over the line wire of a number of separate musical tones, which are employed for the transmission of an equal number of separate telegraphic messages. These musical tones are sent over the line in the shape of rapid interruptions of the current, obtained by means of tuning-forks, that are automatically vibrated by electro-magnets. The forks are arranged so as to interrupt the circuits of batteries connected with the main line at its sending end. There will, in this way, be sent into the line wire a combination tone, composed of the different

Harmonic multiple telegraphy.

rates of vibration sent into the line. On the arrival of this composite tone at the receiving end of the line, it is resolved into its component tones by instruments called harmonic receivers. These receivers consist of steel ribbons, tuned so as to be capable of readily vibrating under the influence of the electromagnetic impulses received through their magnet coils at one rate only. As the composite tone passes through the coils of a particular electro-magnetic receiver, those impulses only that correspond to the particular tone to which this receiver is tuned are capable of affecting its armature or vibrating reed. Consequently, only those particular notes or vibrations that correspond to a particular key at the transmitting station will affect this particular receiver.

Harmonic receivers.

The harmonic system employs the Morse alphabet. The receiving may be done either by means of sound, or the received signals may be converted into regular Morse characters by means of a suitable device. The Gray Harmonic Multiple System never came into any extended use, owing to difficulties that arose in practice.

In the synchronous system of multiplex transmission, invented by Delany, the division of a single telegraph line has been carried so far as to successfully establish as many as 36 separate divisions of the line, so that it is possible to simultaneously transmit 36 separate messages in one direction, while, at the same time, 36 additional messages can be transmitted over the same wire in the opposite direction. A single line so divided would, therefore, require, when employed to its full extent, 36 operators to transmit and 36 to receive at each end of the line, or 72 in all, while an equal number would be required at the opposite end of the line, that is to say,

Delany's synchronous multiplex system.

Capacity of a single Delany synchronously multiplex line.

a single line so equipped would require 144 operators. For the purpose, however, of sending such messages at the ordinary rate of speed at which an expert operator can transmit Morse characters, it has been found preferable in practice to limit the division of the line to the establishment of six separate Morse circuits in each direction. A line so equipped would require for its operation 12 operators at each end, or 24 in all.

Synchronism.

Let us now examine briefly into this wonderful system of telegraphy as carried out in actual practice. The Delany system requires the employment of essentially the following parts: a circular table of alternately insulated and grounded contacts at each end of a telegraph line, and a rotating arm provided with a trailing contact at each end of the line, driven by means of electro-magnetic devices called phonic wheels. By means of these wheels the trailing arms at each end of the line are maintained in absolutely synchronous rotation, so that whenever the wheel at one end of the line is in a certain position in its rotation, the wheel at the other end of the line will be in a corresponding position. Delany has succeeded in obtaining this synchronism by means of electric impulses automatically sent over the main line in either direction, whenever the wheel at either end fails to rotate in absolute synchronism with that at the other end. In addition to the above there are also needed transmitting and receiving instruments connected with similar contacts at each end of the main line, and forming practically separate and independent lines for the simultaneous transmission of messages over the main line in either direction.

The sending and receiving stations are represented at X and Y, respectively, Fig. 152. Similar appa-

ratus are employed at each end of the line. A steel tuning-fork, *a*, at each station, is continuously vibrated by the action of a magnet, A, whose coils are connected with the circuit of the local battery LB.

Action of Delany's synchronous multiplex system.

FIG. 152.—Delany's Synchronous Multiplex Telegraphy.

This circuit is rapidly made and broken by means of platinum contacts x and x', placed on the ends of the fork, which, in its vibration, makes and breaks the circuit with opposing contact springs at y and y'. The makes and breaks so established, open and close the circuit of another local battery placed in

the circuit of the electro-magnet D, by means of which the transmission apparatus C is maintained in continuous rotation.

The main line Q Q has each of its ends connected with the trailing finger F, of the transmitting and receiving apparatus at each end of the line, as shown. As the arm rotates over the plate C, the finger F is brought into successive electric connection with the series of insulated contacts on the upper face of the table F'. Any number of separate contacts can be placed on this table, 60 of such contacts being shown in the figure. These contacts are connected with the separate circuits that it is desired simultaneously to maintain. The 60 contacts are placed in six separate and independent circuits of ten contacts each, as will be seen in the figure, at either the transmitting or the receiving station.

Connection and action of receiving circuits.

In Fig. 153, which represents the working of the receiving circuits, only four of these circuits are shown for the sake of clearness. R, R^1, R^2, R^3, are polarized relays, while S, S^1, S^2, S^3, are the ordinary Morse sounders. The connections with the main battery MB, and the local battery LB, are as shown. Since the relays at the distant station are connected with the same corresponding numbers of contacts as at the receiving station, when the trailing contact finger at each station simultaneously touches the contacts bearing the same numbers, the corresponding instruments connected with these sets of contacts will be placed in communication over the main line, as so many separate wires or circuits, provided, of course, that absolute synchronism is maintained between the two trailing contact arms.

The following experiment, which has been successfully tried on a working wire established be-

tween Boston and Providence, shows the complete manner in which Dr. Delany's synchronous multiplex system has been carried out in actual practice, and how closely he has been able to maintain the synchronism between the two travelling arms. There is appended the following description of this experiment from a paper printed by the Author in the Journal of the Franklin Institute, in August, 1884:

"Wishing to try the adaptability to the synchro-

Fig. 153.—Working of Receiving Circuits in Delany's Synchronous Multiplex System.

nous system, of the automatic repeaters employed by other telegraphic systems, whereby great distances are overcome, Mr. Delany, on three different occasions during the past two weeks, successfully employed such repeaters with his system, the last trial, viz., that on Monday, the 14th of July, being witnessed by myself.

Remarkable experiment in synchronous multiplex telegraphy.

"One of the two wires erected by the Multiplex Company between Boston and Providence was divided into six separate and distinct Morse circuits.

The first of these circuits, which we will call No. 1, was operated to Providence, at which place the receiving relay, on that circuit, was connected to the transmitting instrument on No. 2 circuit. In Boston the receiving relay of No. 2 circuit was connected to the transmitting instrument of No. 3 circuit. In Providence, the receiving relay of No. 3 circuit was connected to the transmitting instrument of No. 4 circuit. In Boston, the receiving instrument of No. 4 circuit was connected to the transmitting instrument of No. 5 circuit. Finally, in Providence, the receiving relay or instrument of No. 5 circuit was connected to the transmitting instrument of No. 6 circuit. Under these arrangements, the transmitting instruments at both stations were operated by the receiving relays on the other circuit the same as if worked or operated by an operator; in other words, the six separate and distinct circuits, established by the synchronizing apparatus between Boston and Providence, were arranged so as to form in reality a continuous wire stretched six times between Boston and Providence, with both of its free ends in Boston.

Splendid action of apparatus.

"Mr. Delany then transmitted a message on the No. 1 circuit from Boston to Providence, which was automatically retransmitted from Providence to Boston on No. 2 circuit; again automatically retransmitted from Boston to Providence on No. 3 circuit; again automatically retransmitted from Providence to Boston on No. 4 circuit; again automatically retransmitted from Boston to Providence on No. 5 circuit, and finally automatically retransmitted from Providence to Boston on No. 6 circuit. Or, in other words, the message sent from Boston on the first circuit went to Providence, came back to Boston, again went to Providence and came back to Boston, when it again went to Providence and came back to

Boston, at which final station it was clearly read by an operator without the loss of a single character, or the slightest impairing of its original clearness, and without the aid of any person except the transmitting operator on the No. 1 circuit in Boston, and the receiving operator on the No. 6 circuit in Boston. All this was done over one and the same wire, so that the message travelled in its back-and-forth journeys between the two cities about three hundred miles, or six times the distance between the two cities."

Works best in damp, foggy weather.

It is an interesting circumstance, that, in the practical operation of the Delany system in England, it has been found that the operation is better in wet or foggy weather than it is in clear, dry weather. This is probably due to the fact that such weather permits a ready discharge of the line, which is thus rid of its previous charge.

CHAPTER XIX

SUBMARINE TELEGRAPHY

"The submarine telegraphs of the world number 1,750. Their aggregate length is nearly 200,000 miles; their total cost is estimated at $275,000,000, and the number of messages annually transmitted over them at more than 6,000,000. All the grand divisions of the earth are now connected by their wires, and from country to country and island to island the thoughts and words of mankind are instantaneously transmitted. Beneath all oceans save the Pacific [written before the laying and use of the Pacific cable] the universal language which this system has created flows uninterruptedly, and man talks as face to face with his fellowman at the antipodes. Darkest Africa now converses daily with enlightened Europe or America, and the great events of the morning are known in the evening throughout the inhabited world. Adding to the submarine lines the land-telegraphic systems by which they are connected and through which they bring interior points of the various continents into instantaneous communication, the total length of telegraph lines of the world is 1,180,000 miles, the length of their single wires or conductors 3,800,000 miles, and the total number of messages annually sent over them about 400,000,000, or an average of more than 1,000,000 messages each day."—*Bureau of Statistics of Treasury Department, U. S. A.*

Submarine telegraphy.

SUBMARINE telegraphy, or, as it is sometimes called, cable telegraphy, consists, as the word indicates, in the transmission of intelligence through suitably insulated cables, placed under the surface of a body of water. Such cables are sometimes distinguished as sub-aqueous cables, when they are laid across rivers or other bodies of fresh water, and submarine cables when they are laid on the bottom of the ocean.

Some early history of submarine telegraphy.

The earliest attempt at the transmission of signals through submarine cables dates back to 1839. Here, however, the insulating material employed consisted simply of cotton or hemp, coated with asphaltum or

PATROL BOX OF POLICE SIGNAL SYSTEM AT WORLD'S FAIR

The box contains telephone apparatus for reporting the patrolman's rounds; means for ringing a "hurry" call for a wagon; a bell which answers this call, and heavy gongs for calling the officers to the box at any time, for instructions from the central office

tar, and, as we can now readily understand, such a wire was only capable of transmitting signals for a comparatively short time. Nor were any of the numerous subsequent attempts made between 1839 and 1849 any more successful, until gutta-percha was employed as the insulating material. The first submarine wire insulated with gutta-percha, at least so far as the United States is concerned, was laid across the Hudson River between New York and Jersey City in 1848. This wire, however, was furnished with no protective covering other than that of the gutta-percha itself, and, consequently, soon failed.

The Dover-Calais cable

The first submarine cable was laid across the English Channel between Dover and Calais in 1850. This was also an unprotected cable, consisting of a single strand of copper wire covered with gutta-percha. It worked successfully for a single day, and then failed. Undeterred, however, by this failure, the cable was relaid in 1851, and this time successfully, for it took the shape, as we shall hereafter see, that it is necessary for successful submarine cables to have; viz., that in which a number of separate conducting wires are suitably protected by an armor of heavy wires on the outside.

The idea of an Atlantic cable.

It has only been by means of the experience gained as a result of the many failures of the early submarine cables that were constructed in the years between 1853 and 1858, that the submarine cable of to-day has reached its present highly effective condition. The fact which was at last satisfactorily established, that telegraphic communication could be maintained for a practically indefinite time through cables extending under the ocean for distances of several hundred miles, led to the then bold project

of attempting to establish telegraphic communication between Europe and America by means of a submarine cable resting on the bed of the Atlantic Ocean. Before, however, proceeding to a history of this great undertaking, it will be well to examine somewhat more fully into the peculiarities of the submarine cable employed so extensively to-day in most of the oceans of the world.

Construction of submarine cable.

The submarine cable consists of a central conductor, formed of a number of strands of copper wire, and insulated by gutta-percha applied in several successive layers. On the outside of the gutta-percha is placed a layer of hemp, known technically as the bedding. This is provided for receiving the outer or protective envelope, generally formed of iron wires, and called the armor or shield. A submarine cable, therefore, consists of four distinct parts; viz., the central conducting wire or core; the insulating material surrounding such core; the bedding of hemp or other material surrounding such insulating material; and finally, the protective envelope. The core is now invariably made of several strands, it being considered that there is less danger of entire continuity being lost by an accident to the cable. The size of the core will depend on the length of the cable and the speed with which the messages are to be transmitted through it, a small, long core having a much lower speed or rate of transmission than a short, thick core.

Deep-sea cable and shore-end cable.

The submarine cables consist of two distinct parts; viz., the part which is to be laid in the deep water of the sea, which is called the deep-sea cable, and the part which lies in the water near the shores, called the shore-end cable. Since the latter part of the cable is exposed to the action of the waves on a rocky bottom, which might injure the cover by

abrasion, it is necessary to provide for this part of the cable a heavier sheathing or armor than for the deep-sea cable. This difference in weight may be nearly 6½ times greater in the case of the shore-end cable, the weight of each being in the case of one particular cable 12 tons to the nautical mile for the shore-end, and 1.8 tons to the nautical mile for the deep-sea part of the cable.

A submarine cable.

An example of a submarine cable is given in Fig. 154. It represents one of the Atlantic cables. Here the cores are formed of several strands of copper

FIG. 154.—Submarine Telegraph Cable. Note the heavy wires employed in the armor or shield.

wire, insulated by four separate coatings of gutta-percha. On this is placed a covering of tarred hemp, and finally, on the outside, a number of iron wires covered with hemp. A cross-section of the cable is represented at the bottom of the figure.

Submarine cables act as condensers.

It will be observed that a submarine cable in reality constitutes a condenser, one coating of which is formed by the conducting cores and the other by the iron sheathing and the surrounding water, the di-

electric being the gutta-percha. The specific inductive capacity of the cable, or the extent of the charge it is capable of accumulating, will vary with the character and extent of the materials employed for insulating, as well as with the distance between the two separate coatings. Copper wire of the highest conductivity only is employed for the core.

Excellent qualities of gutta-percha for submarine cables.

There is no substance yet found that equals gutta-percha as the insulating material for a submarine cable. As we have already seen, this material is entirely unfit for underground cables employed for the telegraph and telephone services in large cities, owing either to the variations in the temperature, or to various other destructive agencies to which such cables are apt to be exposed. But for a cable laid in the waters of the deep ocean, there is yet to be discovered an insulating substance that will maintain its high powers of insulation for such an indefinitely long time as will gutta-percha. This immunity from deterioration is, probably, owing to the fact that, at the bottom of the deep sea, the temperature not only remains constant all the year round, but is a comparatively low temperature; viz., that of the maximum density of ocean water. Moreover, a properly constructed cable is, under these circumstances, entirely freed from the action of any corrosive agencies, since the character of the surrounding water remains practically the same all the year round.

Favorable temperature of ocean's bed.

Accidents to submarine cables.

A submarine cable, when properly laid, unless disturbed by some accident, remains intact for a long time; indeed, barring accidents, for a practically indefinite time. But there are, unfortunately, numerous accidents that may occur to submarine cables, against many of which it is difficult to provide. One of the most evident of such dangers is that

which arises from the rupture of the cable, which may be caused by a ship's anchor. Practically, there is no part of the shallow water of the ocean in which a vessel may not occasionally anchor, so that this danger is nearly always present. A ship may readily, during a heavy storm, drag its anchor, and thus break even the strongest cable.

Ships' anchors.

Another danger arises from the constant chafing of the cable on the rocky bottom in places where the cable is markedly exposed to the rising and falling of the tide. This chafing action in time will suffice to wear away the strongest cable. It is both for this reason, and to render the cable less apt to be broken by an occasional anchor, that the shore end is, as we have already pointed out, provided with a greater thickness of armor or sheathing than the deep-sea part.

Chafing by tidal movements.

A curious and unlooked for danger was discovered in the case of the Levant cable, which was laid in 1858, and taken up in 1859, on account of a failure in its action. It was then found that the cable had been attacked by millions of small shell-fish; together with great numbers of small worms, which had almost completely destroyed the unprotected hemp sheathing, and had even eaten their way into the gutta-percha or insulating material. Huxley, to whom a sample of this cable was sent for examination, reported as follows:

Dangers from xylophaga.

"The specimens you have sent me remove all doubt as to the nature of the mischief-maker in the cable. It is a bivalve shell-fish, the xylophaga, closely allied to the ship worm (teredo), but distinguished from it, among other peculiarities, by not lining its burrow with shelly matter. The xylophaga turns beautifully cylindrical burrows, always against

Huxley on the xylophaga.

the grain, in wood; and I have no doubt it perforated the hempen coating of the cable in the same way. On meeting the gutta-percha it seemed not to have liked it, and to have turned aside, thus giving rise to the elongated grooves which we see. Nothing is known, so far as I am aware, of the range in depth of the xylophaga, so that I can not answer your inquiry as to whether it is probable that cables immersed in 600 to 2,000 fathoms of water would be attacked or not."

The xylophaga and gutta-percha.

The opinion expressed by Prof. Huxley as regards the dislike of the xylophaga (wood-eaters) for gutta-percha has been discredited by the fact that a cable taken up in Kurrachee Harbor was found to have been eaten away not only at the woody fibre of the hemp, but also at the gutta-percha itself. It is an interesting fact that this low order of animal life, the xylophaga, should be able to recognize, under such strange surroundings, in the woody fibre of the hemp, a material similar to that of the wooden ships' bottoms that had for so many generations constituted the chief article of their diet.

Xylophaga and the Atlantic cable of 1858.

The danger from the xylophaga appears to exist in all latitudes, and indeed, to a great extent, in all depths in the ocean; for, when, in 1865, a repair was made in a portion of the Atlantic cable of 1858, it was found that where the iron sheathing had been dissolved away, the gutta-percha had been attacked, since, as the report as to its condition states, "where the core has been bared there are distinct marks of worms, such as one sees in very old hard timber, or in the rich calf binding of old folios in a library."

There are cases on record where a submarine cable has evidently been attacked by some vicious monster of the deep, which has apparently mistaken the strange

intruder into his domain for some new species of enemy. In the case of a cable laid between Penang and Singapore, in December, 1870, and which was stopped by a serious fault during the following March, it was found, on raising the cable, that, at a point some 300 miles from Singapore, the cable had been pierced in the middle by some animal, as was evident from the fact that pieces of bone were still imbedded in the hole. An examination of this fault afterward led to the belief that the attack had been made by a species of sword-fish.

The Singapore cable and the sword-fish.

But a most curious case of interference with a submarine cable is related by Preece, in regard to one of the cables laid in the Persian Gulf:

"The soundings at the fault were very irregular, with overfalls from 30 to 70 fathoms. On winding in the cable unusual resistance was experienced, as if it were foul of rocks, but, after persevering for some time, the body of an immense whale, entangled in the cable, was brought to the surface, where it was found to be firmly secured by two and a half turns of the cable immediately above the tail. Sharks and other fish had partially eaten the body, which was rapidly decomposing, the jaws falling away on reaching the surface. The tail, which measured fully 12 feet across, was perfect, and covered with barnacles at the extremities.

Cable in the Persian Gulf and the whale.

"Apparently the whale was, at the time of entanglement, using the cable to free itself from parasites, such as barnacles, which annoy them very much, and the cable hanging in a deep loop over a submarine precipice, he probably, with a fillip of his tail, twisted it round him, and then came to an untimely end."

A novel submarine scratching-post.

The first submarine cable crossing an ocean was that laid in 1858, by Cyrus W. Field, across the

Cyrus W. Field.

Atlantic between Ireland and Newfoundland. This cable, unfortunately, lasted only for a few weeks. Owing to its great length for these early times, there were necessarily many imperfections in its construction, which caused it to fail after this short service. Its ability, however, to send and receive intelligible signals, even if only during the few weeks of its commercial existence, was sufficient to encourage Mr. Field and his associates to continue their efforts, and eventually to lead to the successful laying of the Atlantic cables of 1865 and 1866.

Intelligent pluck as manifested in laying of Atlantic cable.

It is a difficult matter thoroughly to understand and appreciate the many serious obstacles that had to be overcome in order successfully to establish communication between different countries by means of cables laying on the bed of the ocean. Although Mr. Field was associated with other able men, it is generally acknowledged that it was to Field's energy and perseverance, as well as to a Yankee characteristic, intelligent pluck, that the world is to-day indebted for what was, perhaps, one of the greatest achievements in the practical electric arts; viz., the final establishment of cable communication between the Eastern and Western continents. It will be profitable, therefore, to go somewhat in detail into the early history of this great enterprise. Had it been originally undertaken by men of less intelligence, energy, and pluck, the world might even to-day have been without that delicate metallic cobweb which is doing so much to hasten the day when all the nations of the world will be joined together in one great brotherhood.

It is a comparatively unimportant matter as to who was the first to conceive of the general idea of

an Atlantic cable, since the greater credit undoubtedly belongs to the man who was first able to carry such an idea into actual practice. It seems that in 1851, a Mr. Gisborne, who had been engaged as an engineer in laying telegraph lines through some of the eastern parts of Canada, conceived the idea of extending a telegraph line across the island of Newfoundland. In 1852, Gisborne obtained a charter for a company, called the Newfoundland Electric Telegraph Company, which was to have during a period of thirty years the exclusive right to erect telegraphs in Newfoundland. This company erected some forty miles of this line, when, being unable to obtain any further financial help, the company failed, and Gisborne suffered severe financial loss. Gisborne apparently never entertained the idea of extending a submarine cable from Newfoundland to Ireland, for the charter of the Newfoundland Electric Telegraph Company referred to the fact that the company expected to bridge the gap of the Atlantic by means of fast steamers. It is true that, in after years, he claimed that he had intended to lay a cable also across the ocean. This, however, is an unimportant matter, since, as early as 1841, Morse had expressed a deliberate conviction, founded on experiments, that "a telegraphic communication might, with certainty, be established across the Atlantic Ocean." We only refer to Mr. Gisborne's telegraph line across the island of Newfoundland because it formed a part of the history of Mr. Field's connection with the laying of the first Atlantic cable.

Gisborne and the telegraph line across Newfoundland.

In 1854, Gisborne went to New York for the purpose of obtaining capital to complete the Newfoundland telegraph. While there he came in contact with Mr. Field, to whom he explained the idea of

Gisborne meets Field

shortening the time of communication with Europe by means of a telegraph line across Newfoundland, with communication between the island and Europe by means of carrier pigeons and swift steamers. The idea interested Field, who, however, soon conceived the broader idea of not only connecting such a telegraph line with the City of New York, but also of laying a cable across the Atlantic.

Preliminary steps.

As a cautious business man, Mr. Field at once took steps to satisfy himself concerning the following points; viz., first, as to whether there were any mechanical difficulties that would prevent him commercially from carrying out the plan of a cable across the Atlantic. For example, as to whether the character of the bottom of the ocean between these two points was of such a nature that difficulties might be expected to arise from the action of the waves, volcanoes, or ocean currents; and, second, as to whether there were any electric difficulties that would prevent telegraphic communication being established through so long a cable as would be required to connect Newfoundland with Ireland.

Letters of Field to Maury and Morse.

The business sense and ability of Field were manifested by the systematic manner in which he went to work to inform himself concerning these points. He at once wrote a letter to Lieutenant Maury, who was then at the head of the National Observatory at Washington, as to the difficulties he might expect to arise from the ocean, and another letter to Morse, as to whether in his judgment it would be possible to establish telegraphic communication through so long a cable. The answers received were prompt and satisfactory. Maury replied by sending a copy of a letter he had prepared for the Secretary of the United States Navy on the same

subject. In this letter Maury pointed out the fact that the greater part of the distance between Newfoundland and Ireland, some 1,600 miles, was occupied by a plateau eminently suitable for receiving a cable. The surface of this plateau, instead of being covered with granite, or with hard angular rocks, was covered with a fine ooze, consisting of countless microscopic shells. In referring to this matter, Maury speaks as follows:

"But whether it would be better to lead the wires from Newfoundland or Labrador is not now the question; nor do I pretend to consider the question as to the possibility of finding *a time calm enough, the sea smooth enough, a wire long enough, a ship big enough,* to lay a coil of wire sixteen hundred miles in length; though I have no fear but that the enterprise and ingenuity of the age, whenever called on with these problems, will be ready with a satisfactory and practical solution of them.

Maury on an Atlantic cable.

"I simply address myself at this time to the question in so far as *the bottom of the sea* is concerned, and as far as that goes, the greatest practical difficulties will, I apprehend, be found after reaching soundings at either end of the line, and not in the deep sea. . . .

"A wire laid across from either of the abovenamed places on this side will pass to the north of the Grand Banks, and rest on that beautiful plateau to which I have alluded, and where the waters of the sea appear to be as quiet and as completely at rest as it is at the bottom of a mill-pond."

An equally favorable reply came from Morse. Field at once set to work to associate himself with a number of men of capital, energy, and intelligence. This was finally done, but it will readily be understood that it was not by any means in a sin-

Organization of the New York, Newfoundland and London Telegraph Company.

gle day. A company was formed that bought up the old charter of the Newfoundland Electric Telegraph Company, and succeeded in having this charter replaced by another, that was called the New York, Newfoundland and London Telegraph Company. It is an interesting fact, as showing the integrity of the people who were associated in this great enterprise, that one of the first actions the Board of Directors of the new company took was to draw on New York for $50,000, and pay off in full the debts of the old company.

As showing the difference between the new and the old companies, it will be interesting to note the following words taken from the charter of the Gisborne Company; viz.:

Extract from charter of the Gisborne Company.

"The telegraph line of this company is designed to be strictly an 'Inter-Continental Telegraph.' Its termini will be New York, in the United States, and London, in the Kingdom of Great Britain; these points are to be connected by a line of electric telegraph from New York to St. John's, Newfoundland, partly on poles, partly laid in the ground, and partly through the water, *and a line of the swiftest steamships ever built from that point to Ireland.* The trips of these steamships, it is expected, will not exceed five days, and as very little time will be occupied in transmitting messages between St. John's and New York, the communication between the latter city and London or Liverpool will be effected *in six days* or less. The company will have likewise stationed at St. John's a steam yacht, for the purpose of intercepting the European and American steamships, so that no opportunity may be lost in forwarding intelligence in advance of the ordinary channels of communication."

In contrast with this, note the following brief

extract from the charter of the New York, Newfoundland and London Telegraph Company:

"Whereas, it is deemed advisable to establish a line of telegraphic communication between America and Europe by way of Newfoundland."

The first work of the new company was to complete the telegraph line across the island of Newfoundland. This was finally accomplished, but only after considerable difficulties, so that there was thus completed the first part of the great enterprise; viz., direct telegraphic communication with the eastern part of the island and the City of New York. This, however, was the least difficult part of the undertaking. The inability to peer into the future is not infrequently a fortunate circumstance. Had the projectors of this great enterprise any idea of the continued disappointments and failures they were to meet in carrying out their work, there is but little doubt that such work would never have been attempted. It will be impossible, in the brief space that can be given to this matter, to attempt to follow all the preliminary details. We must, therefore, pass over the time spent by Field in obtaining the necessary financial aid, not only from private individuals, but also from the governments of England and the United States. Nor can we make any reference to the many changes that were necessary in the organization of the company, or in the extent of its capital, in order to continue the work after the repeated failures that occurred before the Atlantic cable was finally laid. It will suffice to say that, in 1857, Field had succeeded in getting the necessary cable manufactured and safely stowed away in the holds of two ships, one an American ship, the *Niagara,* and the other a British ship, the *Agamemnon.*

Completion of telegraph line across Newfoundland.

Difficulties.

The above-named ships met at Valencia Bay, Ire-

land, on August 5, 1857. It was decided that the *Niagara* should lay the first half of the cable from Ireland to the mid-Atlantic, and the end of the cable should then be spliced with the cable on the *Agamemnon*, which should lay the remaining half. The ships left the Irish coast and things went smoothly but for a short time. When only five miles from land, the heavy shore-end of the cable got caught in the machinery employed for laying it, and parted. It was, however, recovered, and spliced, and the vessels again sailed westward until some 200 miles of cable had been paid out, when the signals suddenly failed, with the cable in some 1,750 fathoms of water. After making several efforts to locate the trouble, they were about to cut the cable and abandon the enterprise, when the electric continuity was suddenly restored. The cause of this mysterious fault has since been ascribed as being possibly due to the fact of the insulating gutta-percha parting under the immense strain to which the heavy cable had been put, and afterward coming together, reinsulating the core. The laying of the cable was proceeded with, and all things again went on smoothly, when, some 335 miles from Ireland, after a total of some 255 miles had been laid, the cable suddenly parted, and dropped into the deep water of the ocean, so that this effort was abandoned. This occurred on August 11, 1857.

The attempt of 1857 with the *Niagara* and the *Agamemnon*.

A mysterious fault which mends itself.

Failure.

Undaunted by this great loss, which amounted to some half a million dollars, the telegraph companies decided to continue their efforts in laying the cable, increased their capital stock, so as to obtain money for such purposes, and ordered some 700 miles of additional cable from the manufacturers, in order to make up for the lost cable and supply a surplus in case an increased length were necessitated

by the drifting of the ship. This cable was again safely stowed in the holds of the *Niagara* and the *Agamemnon*. This time, however, it was decided that the two halves of the cable should be simultaneously laid; that the two ships should meet in mid-ocean, splice the ends of their cables, and then proceed to lay the cable in opposite directions, in the meantime, of course, keeping up continual telegraphic communications between the two vessels, and thus continuously testing the conducting continuity of the cable. Accordingly, on the 25th of June, 1858, the vessels met in the middle of the Atlantic, spliced the ends of their cables together, and sailed respectively east and west. Again, however, misfortune met them. When each ship had paid out some forty miles of cable, the testing current showed that electric continuity had again ceased. A testing showed the curious fact that each cable had failed at the same second of time at a distance of less than ten miles from each ship. This, however, was not so serious a matter, and the two ends of the cable being drawn aboard the ships, a new splice was made, and the ships again sailed east and west. When, however, the *Agamemnon* had successfully laid some 200 miles of cable, the current again ceased to flow, and it was discovered that the cable had broken about 20 feet from the stern of the *Agamemnon*. Again, therefore, had the effort failed. The cable was cut from the stern of the *Niagara*, and both vessels proceeded sorrowfully on their return.

First expedition of 1858; the *Niagara* and *Agamemnon* meet in mid-Atlantic and simultaneously lay cable in opposite directions.

The cable breaks from the *Agamemnon* end.

Failure of expedition.

Again, however, intelligent pluck determined the company to make another effort, so that, in due process of time, the same vessels again met in mid-ocean, on July 29, 1858, and after splicing their cables, again sailed in opposite directions. This

The second expedition of 1858.

time the effort was successful, the *Niagara* reaching Trinity Bay August 5, 1858, and the *Agamemnon* reaching Valentia Bay, Ireland, about the same time, Field being on board the *Niagara*. The announcement of this success was made as follows:

Success of expedition.

"About eight o'clock on the evening of the 4th instant, while the *Niagara* was proceeding up Trinity Bay, and some seventeen or eighteen miles distant from the landing-place, Mr. Field left the ship for the purpose of visiting the telegraph station, and if possible of sending a despatch to the United States announcing the success of the enterprise. As the boat of the *Porcupine* was alongside, it was cheerfully placed at his disposal by Captain Otter, who had now undertaken to pilot the *Niagara*. Mr. Field immediately set out, and as the *Gorgon* was on her way to the Bay of Bull's Arm, at the head of which the cable was to be landed, he went on board that vessel, and his boat was taken in tow. Here he was warmly received by Captain Dayman and his officers, who were in the full enjoyment of success. It was near two o'clock in the morning before he arrived at the beach, and as it was quite dark, he had considerable difficulty in finding the path that led up to the station. There was no house in sight, and the whole scene was as dreary and as desolate as a wilderness at night could be. A silence as of the grave reigned over everything before him; while behind, at the distance of a mile, he could see the huge hull of the *Niagara* looming up indistinctly through the gloom of night, and the light of her lamps on her deck making the darkness still darker and blacker by the contrast. He entered the narrow road, and after a journey of what appeared to be twenty miles, came in sight of the station, which stands about half a mile from the beach. There was, however, no sign of life there, and the house, in its

Field carries the glorious news to the workers in Newfoundland.

stillness, seemed strangely in unison with everything around. It had a deserted appearance, as if it had long since ceased to be the habitation of man. In vain he looked for a door in the front; there was no entrance there; he looked up at the windows in the hope, perhaps, of being able to enter by that way, but the windows of the lower story were beyond his reach, and the house having been partly built on piles, gave it the appearance of being raised on stilts. A detour of the establishment, however, led to the discovery of a door in the side, and through this he finally succeeded in effecting an entrance. The noise he made in getting in, it was natural to expect, would arouse the inmates, but there seemed to be either no inmates to arouse, or those inmates were not easily disturbed. He stopped for a moment to listen, and as he listened he heard the breathing of sleepers in an apartment near him. The door was immediately thrown open, and in a few seconds the sleepers were awake, wide awake, and opening their eyes wider and wider as the wonderful news fell upon their astonished and delighted ears. They could hardly believe the evidence of their senses, and were bewildered at what they heard. The cable laid! when but a few short weeks before they had received the news of disaster and defeat, and they had looked only to the far distant future for the accomplishment of the great work. The cable laid, and they unconscious of it—they who had waited and watched so many weary days and weeks for the ships they had begun to believe would never come. What! and they were now in the bay—those same ships—within a mile of them! Can they be dreaming? Dreaming! no—what they have heard is true, all true, and there is the living witness before them.

All asleep.

Enthusiasm

" 'What do you want?' was the exclamation of the

first who was awakened, as he endeavored to rub the sleep out of his eyes.

Help the cable ashore.

" 'I want you to get up,' said Mr. Field, 'and help us take the cable ashore.'

" 'To take the cable ashore!' re-echoed the others, who were now just awaking, and who heard the words with a dim, dreamy idea of their meaning—'To take the cable ashore?'

" 'Yes,' said Mr. Field, 'and we want you at once.'

"They were now thoroughly aroused, and directing Mr. Field to the bedrooms of the other sleepers—for there were four or five others in the house—they prepared themselves with all haste to assist in landing the cable. But the other inmates were already awake, and when Mr. Field made his appearance in the corridor which divides the sleeping apartments on each side of the house, he found them awaiting him in the lightest description of summer clothing. As they had neither pants, vests, coats, shoes nor stockings on, the curious will have no difficulty in discovering in what they were dressed. They were as amazed at seeing Mr. Field as if he were an apparition; and when they recovered themselves sufficiently to ask the meaning of such a strange visitation, they were thrown into another state of wonderment by what he related. When they learned all, they dressed, and prepared themselves for the work before them."

Popular rejoicings on successful laying of cable.

The success of this laying of the first Atlantic cable was heralded with the most extravagant joy on both continents. National rejoicings, illuminations, and popular meetings were held and congratulatory cablegrams exchanged between the two governments. The first message sent was from the Queen of England, and the second from the President of the United States. Public excitement grew stronger

and stronger, and nothing could be said in too great praise for Field and his associates. Now that the great work had been successfully accomplished, many claimants arose for credit for the final success of the enterprise. The stock of the company naturally rose in value and the future seemed painted with the brightest promises, when suddenly, without any warning, the cable utterly failed on the very day when a great celebration of rejoicing had been held in New York City. During the time of its operation, some 730 messages of about 10,000 words were successfully transmitted. The total cost of this cable reached the sum of rather more than one and a quarter millions of dollars.

Complete failure of the cable.

There was naturally a great revulsion of popular feeling at this total failure of the cable after only a few weeks' operation. Doubts were openly expressed as to whether there ever had been any messages received, and it was even hinted that the entire matter was a discreditable effort to permit the directors and other stockholders to unload their shares on the public.

Revulsion of public feeling.

This untimely failure of the cable of 1858 was naturally followed by many years of apparent inactivity. Fortunately, however, during this time much thought was naturally given to the subject of ocean telegraphy, and no little knowledge was gained from the expensive experience of Mr. Field and his associates. There was at least one man, however, who determined that the cable should be laid if it were possible, and this was Mr. Field. He made several voyages across the ocean for the purpose of interesting English capital for the renewal of the enterprise. In the meanwhile, the British Board of Trade had appointed a committee, consisting of the

Field would not abandon the enterprise.

most celebrated electrical engineers in the country, to report on the entire matter. This report was made in 1863, and was extremely favorable.

It will be impossible to enter into details of the work that was accomplished. It must suffice to say that finally a new cable, containing the latest improvements that could be suggested, was constructed and safely placed in the hold of the *Great Eastern* on July 15, 1865, when this vessel sailed from England toward America, paying out the cable as she went. When some 84 miles out, a fault occurred. The cable was successfully drawn aboard the vessel, when it was discovered that a small piece of wire had apparently accidentally caught in the cable, and had cut through its coating until it came in contact with the central core. This was repaired, and the vessel again proceeded westward, successfully paying out its cable, until mid-ocean was reached, when another failure occurred. Fortunately, however, the experience of the past had shown the necessity of the ship carrying with it apparatus that would enable it to lift the cable even from great depths, and on this being done, it was discovered that another similar fault had occurred. It was now impossible to credit this to accident. Evidently a short piece of wire had been intentionally driven through the cable until it made contact with the core, possibly in the interest of some villanous stock-jobbing operation. The trouble, however, was mended, and the great ship passed on, successfully running out its cable until some 1,186 miles of cable had been paid out, when another fault occurred. Here, in endeavoring to take a portion of the sunken cable aboard, it broke, and the cable sunk in the deep waters of the ocean. It is an interesting fact that efforts were immediately made to grapple for the cable, which

Expedition of 1866, with the *Great Eastern*.

An apparently accidental fault.

Malicious mischief.

was several times caught, and once even raised in sight above the water, when it fell, was again lost, and this time finally, since they were obliged to abandon further efforts on account of want of sounding-line. Again, then, the great enterprise had failed. In this case the cost of the cable alone, in cash and the shares of the company, reached the sum of $3,000,000. **Failure of the expedition.**

Again the intelligent pluck of the promoters of this great enterprise manifested itself by determining to lay a new cable and pick up the lost cable and extend it to America. Expeditions for this purpose left England in 1866, with the new cable stowed in the hold of the *Great Eastern*. This time the cable was successfully laid, and placed in actual commercial work. Subsequently, the cable of 1865 was recovered from the depths of the ocean, successfully spliced to a new length, and safely carried to America, thus making two cables across the ocean. The speed of transmission over these cables was, at the beginning, eight words per minute, but was subsequently increased to fifteen words per minute. **The successful expedition of 1866 with the *Great Eastern*.** **Recovery of cable of 1865.**

In this way the great enterprise was completed, but not until after repeated failures, and at a total cost that has been estimated as being equal to at least $12,000,000.

It will be interesting, in this connection, to note the following data concerning the cable of 1865, which was recovered in mid-ocean, and finally successfully laid. The cross-section of the deep-sea part and the shore-end are represented respectively at the upper and lower parts of Fig. 155. The core consisted of seven copper wires, six of which were **Cable of 1865.**

Details of construction of Atlantic cable of 1865.

placed around the central wire in the manner shown. This copper wire had a conducting power equal to 85 per cent of the conducting power of pure copper, which was considered high in those days, but which would never be permitted to pass to-day. The central wire was first covered with an especial insulating compound, known as Chatterton's compound. On this the six additional wires were laid spirally, and another layer of Chatterton's compound applied, when a coating of the best gutta-percha was applied, and another layer of Chatterton's compound

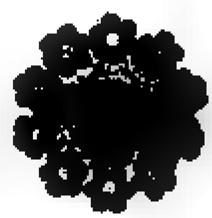


FIG. 155.—Deep Sea and Shore End of Atlantic Cable of 1865. Note the greater size of the shore end of the cable.

was placed on the cable. This was done successively, until some four coatings of gutta-percha were applied. At this step in its manufacture, the cable was carefully tested for electric continuity, after being immersed in water for thirty-six hours. The cable was then wrapped in jute, which had been dipped in caoutchouc, and the wrapping surrounded by ten wires placed in the position shown in the figure.

The shore-end of the cable was the heaviest ever constructed at that time. It was prepared as follows:

The same deep-sea cable was wrapped with a serving of yarn, and was then covered with twelve strands of galvanized iron wire, each consisting of three galvanized wires one-quarter of an inch thick. The weight of this part of the cable was twenty tons to the nautical mile, the entire cable being two and a half inches in diameter. The shore-end was gradually tapered in size to where it was joined on to the deep-sea cable. This shore-end cable extended some 28 miles off the coast of Valentia Bay, where it reached to the depth of 100 fathoms.

Construction of shore-end of cable of 1865.

In closing, it may be well to call attention to some of the information that has only been gained by the expensive experience of the layers of the first cable. It sometimes happens, during the laying of a cable, that a storm arises so severe that there would be danger for the vessel to continue to hold the cable. Under these circumstances, the cable is cut, and, extreme care being taken to close the core water-tight, the cut end of the cable is secured to a length of wire, to which a form of anchor called a mushroom anchor is attached. The cable is then lowered from the ship and secured, as shown in Fig. 156, to a buoy. The particular form of anchor called the mushroom anchor is preferred for such purposes, since it will moor the end of the cable safely without fixing itself so firmly among the rocks as to require too great an effort in order to loosen it. Of course, as soon as it becomes safe to do so, the cable is again taken up into the ship, carefully spliced, and the laying proceeded with in the usual manner.

Temporary mooring of cable during storm.

In order to save time, the shore-end of the cable is generally laid by another ship, so that, when the deep-sea cable reaches this part, it only remains to splice the two cables together.

Some special equipment of cable ship.

The ship that is intended to be used for laying submarine cables is now especially fitted with apparatus required in its work. All cable ships must be furnished with tanks intended to receive the cable, and so arranged that they can be readily filled with

FIG. 156.—Temporary Buoy Mooring of Cable with Mushroom Anchor.

water after the cable is stowed away within them. These tanks are securely attached to the frame of the ship, so as to remain firm in all kinds of weather, and thus avoid danger to the cable from chafing. Large cable or telegraph ships, built especially for the purpose, can readily hold an entire cable capable of spanning the Atlantic Ocean. Such ships require

CALL DEVICE FOR MEMBERS OF THE NEW YORK STOCK EXCHANGE

To find a member on the crowded floor of the Exchange, an electric bell is pressed, causing a hinged card or "drop" on the wall-board to flap over, displaying the member's number. The man sought, if present, repairs to this, his own special bell, to meet his visitor

to be fitted with powerful mechanical apparatus for the purpose of taking up the cable after it has been laid, in order to repair a fault, should such occur during the process of laying. As we have seen, even in the early times when the *Great Eastern* was employed for these purposes, this ship had means for taking up a portion of the cable when a fault occurred. Cable ships, too, are now provided with well-designed grappling apparatus, so that it is a comparatively easy thing to pick up a cable at sea. But in addition to these furnishings, all cable ships

Fig. 157.—Cable Ship at Anchor.

Cable ship with bow sheaves.

contain, both at the bow and stern, large sheaves or grooved wheels, in the shell of a block or pulley, over which the cable runs either when paid out or drawn in. A cable ship provided with such sheaves at the bow-end is seen in Fig. 157.

The number of submarine cables that are now in use in different parts of the world is constantly increasing. There are now some thirteen submarine cables crossing the Atlantic. A cable chart of the world is shown in Fig. 158. An examination of this chart will show that there are numerous submarine cables skirting the shores of South America, Africa,

Fig. 158.—Chart of the World, showing the Principal Submarine Cables.

Australia, and parts of Asia; that cables extend across the Atlantic from Pernambuco, South America, to Europe, by the way of some of the islands that lie northwest of Africa. A number of cables extend through the Mediterranean and Red Seas, through the Indian Ocean, and thence through the islands of the East Indies to Melbourne and Sydney, Australia, and to New Zealand. A cable has been laid across the Pacific Ocean from San Francisco to the Sandwich Islands, and thence to the Philippines.

Cable chart of the world.

CHAPTER XX

OPERATION OF SUBMARINE CABLES

"Upon the progress of submarine telegraphy in the future as in the past a great deal of the world's commerce and industrial progress must depend, and not only the progress of the world collectively, but the relative importance and united relationship of certain parts of it. The constant extension and duplication of the cable and land lines themselves, the fact that the communications have been effected chiefly by Englishmen and retained for the most part in British and American hands, the great reduction made in telegraph tariffs, the improvement in speed and volume of telegraphic traffic may be continued and supplemented by others in the near future. But how and by whom this is to be done, especially whether by men of our race and institutions and in the interests of, or at least not to the detriment of, the continued growth of harmony and union of the English-speaking world —all this depends upon the enterprise as well as the political wisdom and decision of purpose of the present generation."—CHARLES BRIGHT

A sensible time required both to charge and to discharge a submarine cable.

THERE is a popular impression—which, like many other popular impressions, is erroneous—that in so great a conducting wire as a submarine cable extending, for instance, from Ireland to Newfoundland, very powerful electric currents must be employed in order to force the signals through the conductor from one end to the other. This is far from being the case, as we will now endeavor to explain. When one terminal of a battery, or other electric source, is connected with one end of a submarine cable, while the other end of the battery is put to ground, an electric current will continue to flow into the conductor until it is of the same electric pressure or potential as that of the battery. In the case of a short cable, the charge which is acquired in this way will be almost imme-

diately lost or dissipated when the connection with the battery is broken. In the case of a long cable, however, such, for example, as that extending across the Atlantic, a large charge accumulates in the conductor. Consequently, a current will continue to pour out of the cable long after the connection between the battery and the cable is broken. As we have seen, a cable acts exactly like a condenser, and, in the case of a cable extending across the Atlantic Ocean, a condenser of no inconsiderable size. Since the cable lies on the ground, the amount of its charge will be much greater than it would be if it were suspended in the air. Consequently, in the case of a large cable, if a powerful battery is employed, the value of the charge in the cable will be great; and, since no signal can be sent into the cable until the charge it has received is dissipated, the speed of signalling will necessarily be exceedingly small. For this reason, therefore, it is advisable to employ extremely small currents, since, in this way, the time both of the charge and of the discharge is considerably decreased. Another reason for employing a small current arises from the fact that, if a slight imperfection exists in the insulation of the cable, the use of a strong current may cause this leak to increase, and thus bring about the final failure of the cable.

Why it is necessary to employ small currents in working submarine cables.

In the case of the Atlantic cable, when a current is sent into the line from the Newfoundland end, although some little effect is immediately produced at the end in Ireland, yet the current sent into the cable at Newfoundland must continue its charging action on the great Leyden jar, of which the cable consists, so that a very appreciable time elapses before the current strength at Ireland is sufficiently great to produce any decided effect even in the

delicate receiving instrument employed in cable telegraphy. Culley has found as a result of actual tests on this cable that it requires .2 of a second for a current sent into the cable at Newfoundland to sensibly affect the receiving instrument at Ireland; that after .4 of a second, the current has only attained 7 per cent of its maximum strength; and that it is not until some 3 seconds that it has gained its full strength and flows uniformly. Culley thus refers to the retarding action exerted by a cable and the effect produced on signals as follows:

Time required for signalling over Atlantic cable.

"The action of a current in a long cable can be shown in the following way, if a looped cable of sufficient length or an artificial cable is available. A Morse ink-writer is fitted with two electro-magnets and writing-disks; one is placed in a local circuit so as to show the actual duration of the battery contact, and the other at the distant end of the cable to show the signal received. The first will produce the upper line of the following illustrations [our Fig. 159], the second the middle line:

Culley on retardation in submarine cables.

"(A) The instrument will not commence to mark the paper until the current has attained a certain strength dependent on the sensitiveness of the instrument, and it will continue to mark until the current has fallen below that strength.

"(B) When the cable is insulated at the sending end after each signal, so that its charge can escape at the receiving end only; if dashes are sent of the length shown by the upper of the two lines [our Fig. 159], they will be prolonged by the escape of the charge remaining after the cessation of battery contact, so as to form the lower continuous line. The line begins a little late for the reason given in (A).

"(C) When an earth contact is made at the sending end after each signal, so that the charge can

escape at both ends, the prolongation is less, and the received mark shorter. The three dashes will then appear in the middle line thus: [our Fig. 159].

"(D) And if a reverse current is sent after each signal, so as to neutralize a portion of the charge remaining in the cable by electricity of the opposite sign, the prolongation is still less (as in lowest line), and the speed of signalling is still further increased, for it is clear that the upper dashes may be sent at shorter intervals than before."

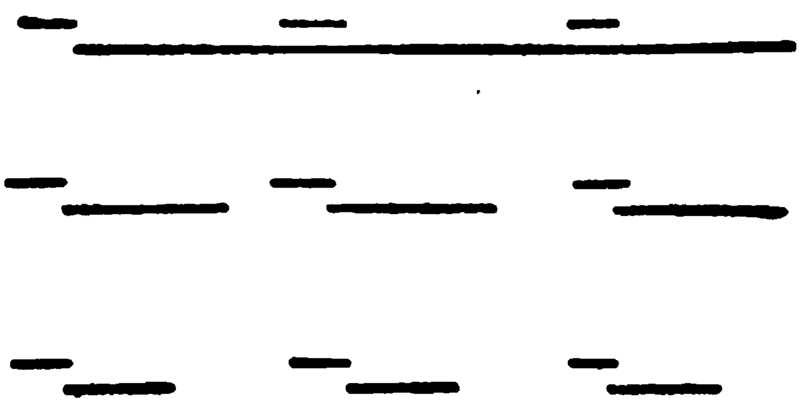


FIG. 159.—Effect of Retardation on Recorded Signals Received over Submarine Cables.

We have seen, in studying the destructive effects of electrolysis in the case of street railway systems employing a ground return, that it is at the points where the electric current passes into the ground from a metallic conductor that such conductor is corroded electrolytically; and that there will be no electrolytic corrosion where such current passes from the ground into the conductor. On the contrary, at such points there is actually a preservation of the conductor from corroding agencies. Now the same thing has been found to exist in the case of submarine telegraphy. When there is a defect in its insulation, the cable will work far better when a positive current is sent through it than it will when a negative current is sent through it, yet an action occurs that will slowly but surely eat its way into the cable; for, as it will be seen, when a positive

Why positive currents tend to destroy a leaky submarine cable.

current is sent through the cable the current passes from the conductor into the earth, but that, when a negative current is sent, the current passes in the opposite direction.

The currents employed in cable telegraphy are generally too feeble to permit Morse apparatus readily to be employed. It has been found preferable to replace the Morse apparatus by the mirror galvanometer, somewhat similar to the form employed by Gauss and Weber. Here the movements of the needle of the galvanometer are caused to deflect a small beam of light over a scale marked on a sheet of white paper. The current passing through the galvanometer coils in one direction, say a negative current, deflects the spot of light to the left, while a current in the opposite direction, or a positive current, deflects it to the right. Using the same signals as are employed in needle instruments, the dot will be represented by a movement of the spot of light to the left, that is, a negative current, while a dash will be represented by the movement of the needle to the right, or a positive current. The cable operator learns to read these movements of the needle just as the operator with the Morse instruments learns to recognize the dots and the dashes by the sounds produced by the instruments.

Some cable receiving apparatus.

In order readily to obtain the positive and negative currents required in sending the characters through a cable, a form of cable sending key is necessary. Such a key consists essentially of two finger keys, operated by the first and second fingers of the hand. Two metal pieces connected with the ends of these two keys are connected respectively to the end of the cable and to the ground. The sending battery has its positive or copper pole so

Cable sending key.

connected with metallic pieces that when one key is depressed it breaks the circuit of the line and connects the copper end of the battery to the line, and the zinc end to the ground, thus sending a dot signal into the line, and when the key is released the line is grounded. When the other key is depressed, the zinc pole is similarly connected to the line and the copper pole to the ground, thus sending a dash signal into the line. The rate of signalling by an expert operator varies from 20 to 30 words per minute.

In a receiving apparatus in general use on many lines of submarine cables the combined weight of the mirror and the magnet is only from one-half to three grains. By the use of a short suspension and a strong directing magnet, the movements of the needle are nearly dead beat, the needle coming quickly to rest after being deflected by the current. A condenser is placed between the cable and the receiving instrument. The use of this condenser is for the purpose of avoiding disturbances of the receiving instrument from the earth currents. Some idea of the great sensitiveness of the receiving instrument may be obtained from the fact that a voltaic cell, consisting of a single empty shell of a percussion cap, filled with some electrolytic liquid, in which a small zinc rod is immersed, will furnish current of sufficient strength to send a message across the Atlantic. Generally, however, much stronger currents than these are employed, since, within certain limits, the signals pass with greater certainty when somewhat stronger currents are employed.

The great sensitiveness of mirror receiving apparatus

The connections of the various apparatus necessary for cable signalling are represented in Fig. 160,

arranged for signalling between Newfoundland and Valentia Bay, Ireland. A condenser at C is placed between the cable and the receiving instrument at Ireland. In this particular case, the condenser consists of some 40,000 square feet of condensing surface. Either the transmitting key T, or the receiver or galvanometer G, can be readily connected with the cable K by means of the switch *e,r,t*. The key T is the double-sending key before described, connected to the zinc and copper ends of the battery B, so that *a* sends a positive and *b* a negative current

Connections of apparatus for signalling across the Atlantic.

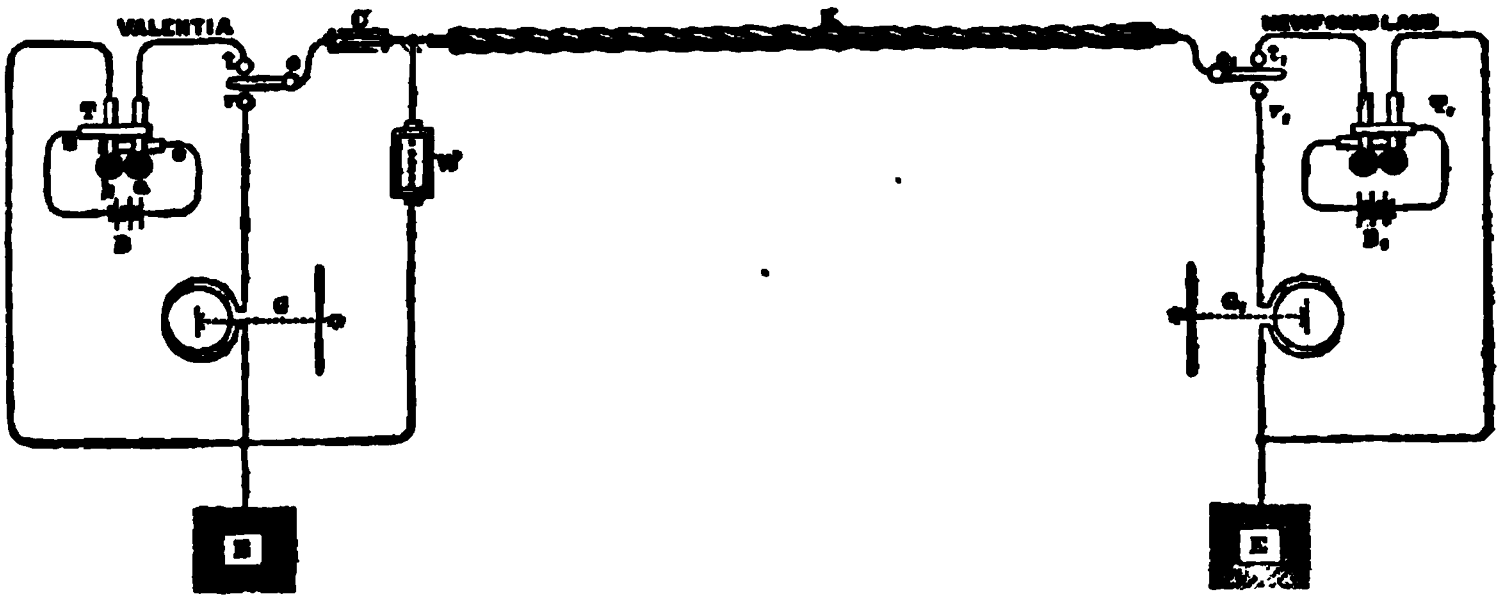


FIG. 160.—Connections of Valentia-Newfoundland Cable to Transmitting and Receiving Instruments.

into the line. A regulable resistance, W, is placed, as shown, between the end of the cable and the earth. Suppose, now, that Valentia wishes to send a message to Newfoundland. The switch is moved so as to connect *t* and *e*. On the depression of the key T, positive or negative impulses are sent into the condenser at C. Let us suppose, for the sake of illustration, that it is the key *a* which is depressed. Then a positive charge is sent into one set of plates of the condenser, and a negative charge is attracted and condensed on the other set of plates, that are connected through the cable with the ground at Newfoundland. At the same time the positive

charge in the cable is driven toward the Newfoundland end of the line. In other words, the depression of the positive key sends a positive current through the cable toward Newfoundland. This charge, passing through e', r', enters the receiving instrument or mirror galvanometer G′, and sends the spot of light in the direction produced by a positive charge. In the same manner, the depression of the other key sends a charge into the cable that causes the spot of light at the distant end to move in the opposite direction. In this manner, the necessary characters are transmitted over the cable. When Newfoundland desires to transmit a message, a similarly arranged condenser is employed at that station.

Reading the message by the movements of the spot of light over the scale.

It requires no little skill to be able to read the messages received by the mirror galvanometer through the movements of the spot of light over the scale. The time required to rid the cable of its previous charge causes the movements of the spot over the scale to take place in an irregular manner. For example, to send the letter *h*, which, it will be remembered, consists of four dots following one another at regular intervals, the first dot will, probably, cause a decided movement of the spot of light to take place almost completely across the scale; the impulse required for the second dot causes it to move a little further; the third dot moves it forward a still shorter distance; while, in the case of the fourth dot, the movement may be scarcely perceptible. However, long experience has enabled the skilled operator to detect these movements. It is an advantage, however, to be able to leave a record of the movements of the spot of light. This has been done by means of an instrument invented by Lord Kelvin, called the siphon recorder.

Kelvin's siphon recorder is represented in Fig.

Kelvin's siphon recorder.

161. Here light rectangular coils *b, b,* of very fine wire, are suspended by means of a conducting wire *f, f′*, between the poles, N and S, of a compound steel magnet. These poles are strengthened by induction on a stationary soft iron core, *a*. The cable current is sent through the coils *b b* by means of the suspension wire *f, f′*. The movements of the rectangular coil to the right or to the left are caused, through the action of a thread, *k*, attached to *b*, to move a delicate glass siphon, *n*. One end of this siphon dips into a reservoir of ink, *m*, while the other end is

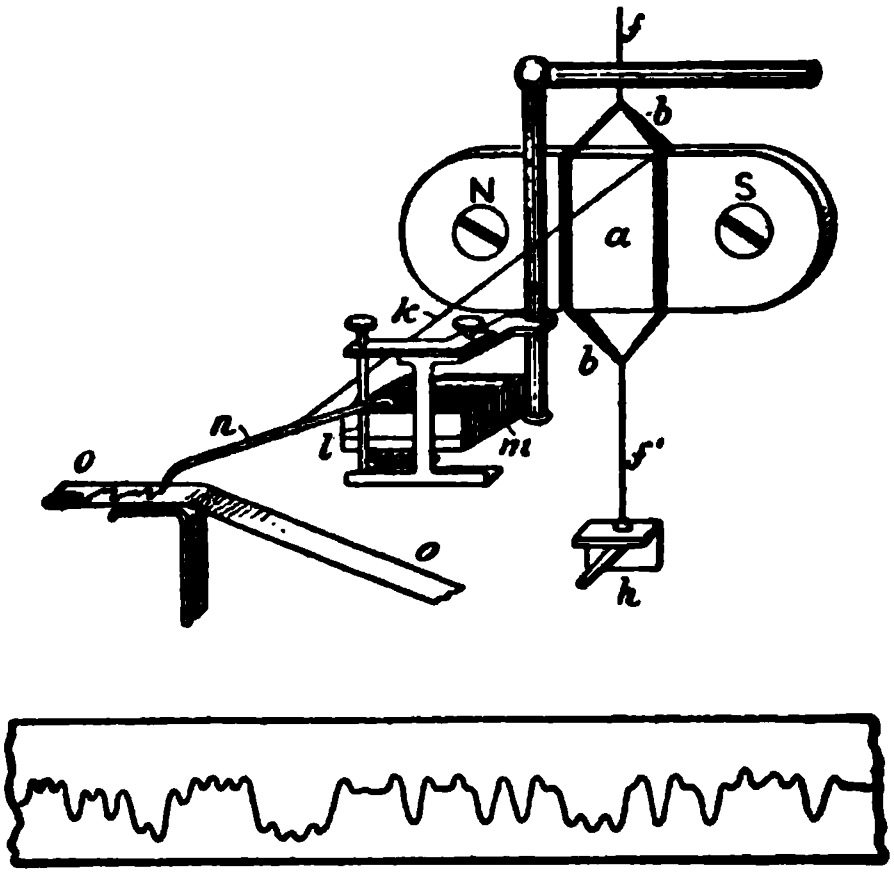


Fig. 161.—Kelvin's Siphon Recorder.

brought very near, but not in contact with, the surface of the paper fillet *o, o*. In this manner there are traced on the surface of the fillet sinuous lines, in which the dots are represented by upward movements, and the dashes by downward movements. A record obtained by the use of this apparatus is represented at the bottom of the figure. Since, in a long cable, the current that passes through the magnet coils is very feeble, it would not be practicable

to permit the end of the siphon to come in actual contact with the surface of the paper, since the friction would be sufficient greatly to retard its movements. In order, therefore, to cause the ink to be thrown out of the siphon, both ink and paper are oppositely electrified, so that the attraction of the opposite charges causes the ink to be thrown out of the siphon in a succession of minute dots. During damp weather, the Kelvin recorder sometimes fails to operate from the dissipation of the electric charges on the paper and ink. Cuttriss has obviated this difficulty by the construction of a siphon recorder in which the siphon is maintained in constant vibration by means of electro-magnetism.

It not infrequently happens, when an apparatus has passed through the experimental stage and come into actual practice, that it takes on a shape in which it would probably not be recognized by its first inventor. Take, for example, the form which the Morse telegraphic recording apparatus and the Wheatstone needle apparatus finally assumed in actual practice. Prescott refers to this matter as follows:

Modifications of Morse, Wheatstone and Cooke telegraphic instruments

"It is somewhat curious that, in the progress of telegraphic improvement, Morse's telegraph, the most valuable feature of which originally was considered to be its capacity for recording communications, should have been modified in practice into an acoustic semaphore, while Cooke's telegraph, originally a semaphore, should at length have been also modified into a recording instrument, in the form which we have just described."

The duplexing of submarine cables.

Nearly all long cables have been duplexed, so as to increase the number of messages that can be transmitted. There is practically no difference be-

tween duplexing cable systems, and duplexing long land lines, only, owing to the greater sensitiveness of the receiving instruments, it is much more difficult to obtain the necessary balance of the line.

Although a great advance has been made in the transmitting and receiving instruments employed in cable telegraphy, there yet remains much to be done in this particular branch of the art. Concerning diplexing, quadruplexing, and automatic repetition of cable messages, Houston and Kennelly, in their book on "The Electric Telegraph," speak as follows:

Houston and Kennelly on diplexing and quadruplexing submarine cables.

"There are no means yet known for either diplexing or quadruplexing a long submarine cable. In the same way, no means have yet been devised for automatically repeating a message from one long submarine cable to another. Short cables can, of course, be operated by Morse repeaters in the usual way, but the signals on a long cable are not only so faint that the receiving mechanism has not the power to make repeating contacts with sufficient firmness, but the distortion of the signals, already alluded to, would prevent such contacts from being properly timed and spaced. When a message is sent from New York to Bombay, it may be sent first from New York to a cable station in Nova Scotia; then from Nova Scotia to Ireland; from Ireland to London; from London to Marseilles; from Marseilles to Malta; from Malta to Alexandria, Egypt; from Alexandria to Suez; from Suez to Aden, and from Aden to Bombay. Consequently, the message by this route would have to be repeated eight times before its final reception at Bombay. Taking the total distance as roughly 10,000 miles, this represents an average of about 1,100 miles at each transmission. There are, therefore, in this particular

transmission, nine places where it is possible to introduce an error or errors into the message.

"It was formerly the invariable practice to write down a message as it was received at each intermediate station and retransmit the message from this written record. A plan has, however, been generally introduced wherever possible, to retransmit messages from the recorder slip without first writing them out. Consequently, the repeating of a message in such a case is performed through the agency of the operator, instead of by automatic mechanism. In other words, the message is received, say at Aden from Suez, on the recorder slip, and is retransmitted by the operator on the next circuit, or to Bombay, as fast as it is received at Aden. At the end of the message, the operator at Aden reverses the connections between the sending and receiving cables, so that he is now able to act as a manual repeater in the opposite direction, or from Bombay to Suez."

Charles Bright on the influence of submarine telegraphy.

The extensive use of the submarine cable has had a considerable influence on the progress of the world. Charles Bright speaks of this influence as follows:

"The great revolution which submarine telegraphy has effected in the world's progress may be regarded from two great standpoints—the political and commercial. Let us begin with the former. In the first place it has accelerated even more perhaps than the improvement in locomotion by land and sea what may be called the practical shrinkage of the globe. The nations and people of the globe, being in continual contact with each other through the telegraph and its powerful ally, the press, know one another and understand one another's actions and thoughts and national aspirations in-

finitely better than they did fifty years ago. The effect of the better knowledge and insight upon their mutual relations may not always be in every instance a happy one, . . . but if the whole world gains, as it undoubtedly does, by closer contact and by the lessons which one nation is thereby induced to learn from another, we should not take to heart any relative, and maybe quite temporary, decrease of ascendency in certain departments of our national activities. . . . .

Political effects of submarine telegraphy.

"One political result of this great development of the world's electric wires which Englishmen may safely regard with unusual satisfaction and pleasure, is the much closer relation which has thereby been rendered possible between the mother country (the United Kingdom) and the daughter nations, English-speaking, English-modelled as to their institutions, and in the main British and Irish stock, which have sprung up in the most distant parts of the world. The 'little England' idea, so fondly cherished by the old Manchester school of economists and politicians (who would gladly have seen all our young and vigorous Anglo-Celtic brood chased as young birds from the parent nest almost before they could fly), is practically as dead as a door nail. In its place we hear on all sides . . . of federations or customs unions between the United Kingdom and its self-governing colonies and India; and grander, if less practicable, than all these, we hear of negotiations for the establishment of a permanent arbitration tribunal for settling peacefully all future differences between the two main divisions of the English-speaking world. . . .

Diplomatic effects of submarine telegraphy.

"Another department in which the submarine cables have produced a notable political effect is the diplomatic. If the peoples have been brought more in touch with each other, so have the rulers

and statesmen. An entirely new and materially improved method of conducting the diplomatic relations between one country and another has come into use with the telegraphic wire and the cable. The facility and rapidity with which one government is now enabled to know the mind, at least the professed mind, of another has often been the means of averting diplomatic ruptures and consequent wars during the last few decades. . . .

"Let us now turn to the commercial results of this great development of submarine telegraphy. These have been partly anticipated in discussing certain improvements in prices of service and speed of transmission, and altogether the subject is so vast, so complicated, and so far-reaching that to attempt a detailed or systematic account of it within the compass of a work like the present would be but presumptuous. The fact is, the methods of conducting business between merchants and financiers in the different countries have been completely revolutionized by the telegraph cable, which places the business man in touch with the new markets of the world. This is so patent to the generation of older business men now living that the younger ones only need reminding of it. Fifty years ago it took a London or Liverpool merchant six months to get an answer to a letter addressed to a correspondent at Calcutta and complete a business transaction. Nowadays, by means of the telegraph, the same transaction can be effected within six hours. Another result of the change and conditions brought about by the wire and cable is the partial elimination of middlemen in some departments of international commerce."

Commercial effects of submarine telegraphy.

CHAPTER XXI

FACSIMILE AND TIME TELEGRAPHY

"What is writ, is writ."
—*Childe Harold's Pligrimage,* Canto IV, Stanza 185

Definition. FACSIMILE telegraphy, as the word indicates, is a method whereby facsimiles or accurate copies of charts, diagrams, pictures or signatures are telegraphically transmitted over a telegraph line from one end to the other.

Bakewell's facsimile telegraph. There are various methods by means of which facsimile telegraphy can be accomplished. One of the earliest of these was that of Bakewell, of London, who, in 1850, invented the system represented in Fig. 162. Here two similar metallic cylinders, *c*, *c'*, placed at the opposite ends of a telegraph line, are maintained in synchronous rotation, while metallic arms or tracers, ***r***, ***r'***, are moved from left to right over the surface of the cylinder. In this way, there is traced a continuous spiral line on the surface of the cylinder. Batteries at B and B' have one pole connected with the metallic tracer and the other pole connected with the earth, while the ends of the telegraph wire between the two stations are connected with the metallic cylinders.

Operation of Bakewell's facsimile telegraph. Suppose, now, that at the transmitting station a chart, writing, or other design which it is desired to transmit, be traced on the surface of the cylinder in varnish or other non-conducting material that will readily dry, and leave a hard surface. Sup-

pose, moreover, that at the receiving end a sheet of chemically prepared paper be placed over the surface of the cylinder similar to that employed in the chemical Morse recorder already described. If, now, the two cylinders be synchronously rotated, whenever the tracer at the transmitting station moves over the non-conducting surface, the circuit will be broken. As long as it remains in contact with the metallic cylinder, the circuit will be complete. It follows, therefore, that there will be traced on the surface of the chemical paper at the

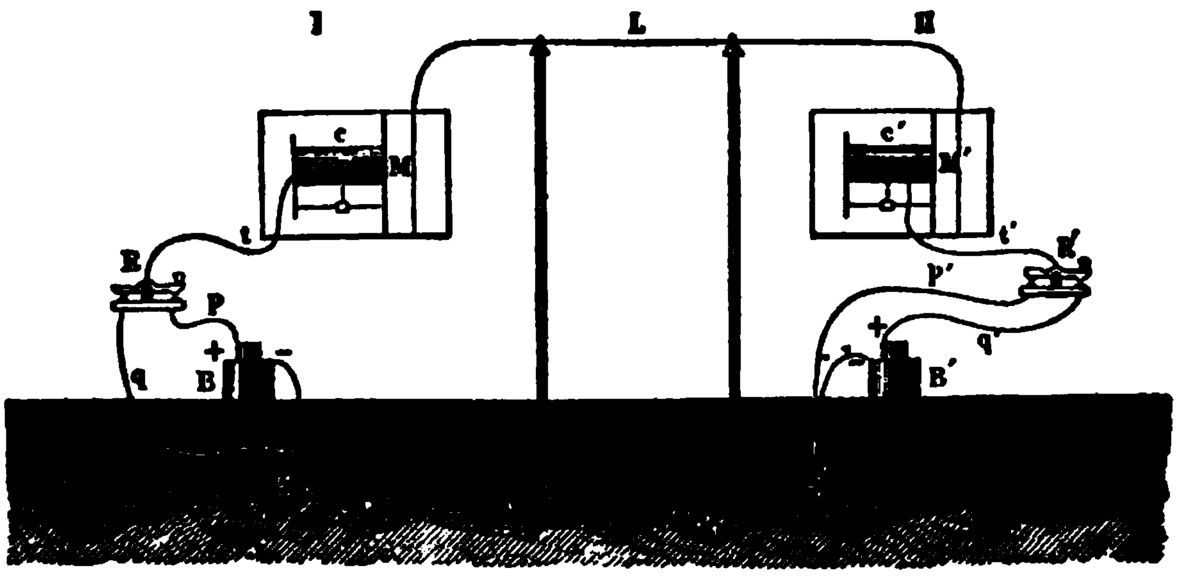


FIG 162.—Bakewell's Facsimile Telegraph.

receiving station a continuous blue line, which will be broken only at the places where the surface of the transmitting cylinder has been covered with the design that is to be transmitted. Consequently, this design will be recorded on the chemical paper of the receiving instrument in white uncolored lines.

The Dennison facsimile telegraph, represented in Fig. 163, is somewhat similar in its operation, only it records the picture in colored marks on a white ground. T and R represent respectively the transmitting and the receiving stations. At each of these stations there is a polarized relay, PR and PR′, employed to maintain a constant to-and-fro vibration

The Dennison facsimile telegraph.

of long metallic arms, *a*, *a'*, attached to their armatures. The extent of these vibrations is limited by set screws, *s*, *s*, and *s'*, *s'*. The vibratory movements are obtained by the generator D, which produces a small alternating electric current. Since the coils of both relays, PR and PR', are in one and the same circuit, the armatures will vibrate in unison or synchronously.

At the transmitting station, the transmitter F has a strip of tin-foil on which the characters are traced with an insulating ink. This strip is caused to move

FIG. 163.—The Dennison Facsimile Telegraph.
(By permission of William Maver, Jr.)

Action of the receiving instrument in the Dennison facsimile telegraph.

with a uniform motion by passing between two cylinders that are driven by any suitable means. At the receiving station there is a fillet of chemically prepared paper, F', that is also caused to move at the same rate under the metallic point *n'*, as represented. In this system two separate circuits are required between the transmitting and the receiving stations, one for the transmission and the reception of the messages, and the other for maintaining in synchronous vibration the armatures of the polarized relays. Both of these circuits are completed through the ground. A contact needle *n* is placed on the arm *a* of the transmitter, as shown, similar to the stylus or pen at *n'*. These pens are kept in contact with the tin-foil

and the paper respectively by the use of delicate springs. A battery at B is, under normal conditions, short-circuited by the arm *a*, the strip of tin-foil, the needle, and the resistance *r*, so that while *n* is in contact with the tin-foil, no current passes into the line. As soon, however, as the transmitting needle, *n*, comes in contact with the insulating portions of the ink on the tin-foil, the short circuit is broken, so that a current passes from the transmitting battery over the line and causes a record to be made on the surface of the chemically prepared paper. It is evident that, under these conditions, the arms at *a* and *a'* being caused to vibrate in synchronism, while at the same time the tin-foil strip and the paper fillet are moved under the vibrating arm, there will be produced on the surface of the chemically prepared paper at the receiving station a facsimile of the chart or picture that has been traced on the tin-foil in non-conducting ink.

Advantages of a multiple transmitting and receiving comb.

Where a single stylus or pen is employed in systems of facsimile telegraphy, the record is necessarily slow. For the purpose of increasing the rapidity of transmitting and receiving, Bonelli introduced a multiple comb, in which there were a number of pens or styluses at each station. The two stations were connected by as many separate conductors or conducting wires as there were separate pens or styluses.

Bonelli's facsimile telegraph or typo-telegraph.

Bonelli styled his particular form of facsimile telegraphy a typo-telegraph. The message to be transmitted was set up in type at the transmitting station M, arranged in a single line, with the punctuation marks and spaces introduced just as in ordinary printing, or as represented in Fig. 164. A

comb provided with five metallic teeth was caused to pass over the surface of the type in the manner indicated in the figure. Each of the teeth was connected with a separate telegraph line, L L, which proceeded to the receiving station. This line is represented as broken in the figure simply for the purpose of indicating a great length between the two stations, but it is formed of five continuous lines. At the receiving station N, the line wires were connected with five metallic styluses, as represented, resting on a strip of chemically prepared paper. As before, the line of type and the chemical paper are maintained in a uniform rotation under the pens or styluses by clock-work mechanism. The appara-

Action of Bonelli's receiving instrument.

FIG. 164.—Bonelli's Facsimile Telegraph or Typo-telegraph. Note the necessity, in this form of facsimile telegraph, of using more than a single wire between the two stations.

tus employed at the transmitting and the receiving stations is of such a nature that a current is sent over the line only during the time that the transmitting pens or styluses are in contact with the conducting material of the type, so that the transmitted message is received in printed characters on the fillet of chemically prepared paper at the receiving station.

Many different facsimile telegraphs, employing a number of separate conducting wires, have been devised. Although such systems are a great improvement on the single-pen system, yet the expense of running and maintaining a number of separate telegraph lines or circuits has prevented their ex-

Objections to facsimile telegraphs with multiple conductors.

tended commercial use. But entirely aside from the expense, there is a more serious objection arising from the interferences in the strength of the momentary signals sent through the separate wires, by reason of the induction produced by the neighboring wires on one another.

The Delany system of synchronous multiplex telegraphy readily lends itself satisfactorily in overcoming both of these difficulties. It is easy with the Delany system to establish a great number of practically separate and independent line conductors over a single conducting wire connecting the two stations. Moreover, these separate wires are entirely free from inductive disturbances. But, in addition to both of these facts, it will readily be appreciated that in any system of facsimile telegraphy, unless the transmitting and the receiving apparatus are maintained in synchronism, the operation of the system would be impracticable. Now, since Mr. Delany has succeeded in maintaining synchronism between the transmitting and the receiving apparatus by means of electric impulses automatically sent over the line in one direction or the other, when either the transmitting or the receiving apparatus falls out of step, such a system especially lends itself to facsimile transmission.

Delany system of facsimile telegraphy.

Mr. Delany has applied his system of synchronous multiplex telegraphy to the system of facsimile telegraphy represented in Fig. 165, where X and Y are the two stations, in this case the apparatus being arranged for transmitting from X to Y. A and B represent the tables of contacts, each being provided with 84 insulated contacts, divided into six series of fourteen each. The twelfth and the thirteenth contact in each series is represented as being discon-

Connections of insulated segments.

nected in the figure, these contacts being reserved for the synchronous correction of the apparatus. Let us suppose that the contacts of the six groups are

numbered from 1 to 14 consecutively, and that all the number 1 contacts are connected together and to a line marked 1, at station Y, and all the correspond-

ing numbered contacts at station X are connected together and to the line wire connecting the two stations. Suppose, moreover, that the number 2 contacts at each station are similarly connected to one another, and to a line marked 2, and so on through the series, the thirteenth and the fourteenth contacts being reserved for synchronism, as already explained. Each of the lines, 1, 2, 3, 4—12, so provided, is connected to an insulated finger or stylus, *f*, that forms a part of the comb which moves over the surface of the transmitting and the receiving instruments at C, C.

If, now, the synchronously moving fingers *a a* move over the contacts, they will simultaneously rest on similar contacts at either end of the line, and thus will establish practically 12 separate and independent lines between X and Y. If the speed of rotation of the trailing fingers be three times per second, the circuit will be completed over each of the 12 lines between the two stations 18 times a second. At this rate a high speed of transmission is possible. Of course, the separate styluses at *f f* are insulated from one another, and the plates C, C, on which the transmitting and receiving styluses respectively rest, are maintained in synchronous rotation.

Establishment of separate and independent lines.

The main battery, MB, at X, has one pole connected to ground and the other to the metallic plate, C, which we will suppose to be the transmitting station. The message, picture, or map to be transmitted, in this case ordinary writing, is traced on the surface of C, with some non-conducting ink in the usual manner, and is received on a sheet of chemically prepared paper at the receiving station. In this case, the message will be recorded as uncolored portions on an otherwise nearly continuous blue ground.

Modification of apparatus.

Instead of producing the facsimile transmission in white on an otherwise colored surface, Mr. Delany has modified the apparatus in a manner similar to some other apparatus we have described, whereby the impression is positively received, that is, in blue on a white ground, instead of in white on a blue ground.

Other forms of facsimile telegraphy.

Besides the forms of facsimile telegraphic apparatus described, there are other devices whereby written or printed characters can be transmitted over telegraph lines from one end of the line to the other. These may be conveniently arranged under the head of facsimile telegraphy, although they operate on entirely different principles. We allude to the writing telegraph and the printing telegraph.

The writing telegraph.

In the writing telegraph, two separate line wires are required between the transmitting and the receiving stations. A correspondent who desires to send a message takes up a pen in the telegraph office and writes the message on the surface of an ordinary sheet of paper, thus obtaining a record of what was transmitted. At the distant end of the line, this message is received by means of a pen that traces on another sheet of paper whatever was written at the transmitting end. So correctly are the movements of the transmitting pen, at one end of the line, repeated at the receiving end of the line that the handwriting is so accurately reproduced as to be readily recognized by any one familiar with the handwriting of the person sending the message. It is possible, therefore, by such an instrument, for a person to telegraph his signature to a check or other paper requiring a personal signature.

Let us now examine the electric means whereby this is accomplished. Although in detail of con-

struction the apparatus is somewhat complicated, yet the principles of its operation are readily understood. Matters are so arranged that the motions of the pen at the transmitting station cause a series of resistances to be either introduced into or removed from the two telegraph wires during its movements while writing. The movements of such pen to the right or to the left are, through the means of a lever, caused to introduce into or remove such resistances from one of the two telegraph lines connecting the two stations, while its movements in an up and down direction, in a similar manner, introduce into or remove resistances from the other line. The movements of the pen in intermediate directions are represented by resistances introduced into or removed from both lines. The impulses thus transmitted over the two lines cause the pen at the receiving station to move in an entirely similar manner over a sheet of paper, and thus to write on it the particular characteristic handwriting of the sender.

Operation of the transmitter and receiver of the writing telegraph.

The transmitting instrument is represented in Fig. 166. The stylus or pen there represented is connected, by means of a metallic rod C, with a suitably arranged series of contact springs, S, S, of steel, placed at the base of the instrument at right angles to each other. A series of resistances, R, R, are connected with the lower ends of these contact springs. B B are two contact bars, provided with platinum contacts that are placed directly opposite the contact springs. The rod C, that is connected with the stylus at its upper extremity, rests at its lower extremity on the base of the apparatus, but is provided with a spring lever at the lower end which permits its free movement. A pressure block at P, fastened to the stylus rod, is so adjusted that

Action of transmitting instrument.

when in its normal position it is in contact with the first spring. As the transmitting pen is moved in writing the despatch, the contact bar varies both the number and the character of the contacts, thus

FIG. 166.—The Transmitter of the Writing Telegraph. Note the mechanical connection of the stylus rod with the two sets of resistance contacts.

introducing into or removing from the two line wires the amount of resistances necessary to send over the line the required impulses.

Action of receiving instrument. At the receiving end of the line, apparatus is employed similar to that represented in Fig. 167. Here two electro-magnets are placed at right angles to each other. The recording pen or stylus is supported on a vertical rod, placed, as shown, in con-

nection with the double armature of the electro-magnets. As the varying currents sent into the line by the movements of the transmitting pen pass through the magnetizing coils of the two electro-magnets, the double armature is caused to move in directions that correspond with the movements of the transmitting pen. Consequently, there will be written on the sheet of paper at the receiving station whatever has been written at the transmitting station. This system is capable of accurately reproduc-

FIG. 167.—Receiver of the Writing Telegraph. Note the two receiving electro-magnets, the movements of whose armatures reproduce the movements of the pen.

ing writing over lines many hundred miles in length. The movements of the receiving pen are continuous, so that the i's can not be dotted or the t's crossed. Writing telegraphs, however, have been produced in which it is possible to raise the pen so as to complete the writing in these respects.

Printing telegraphs.

In the printing telegraph, messages are sent over a telegraph line in such a manner that they are received on a paper fillet in regular printed characters. In some cases, such instruments are arranged so as

to print the message on a sheet of paper in a manner similar to that of a typewritten sheet. Printing telegraphs in the form of stock printers, in which quotations of the sales of stocks and other securities are printed on a fillet of paper, are in very general use.

General operation of printing telegraph.

The general principle of the printing telegraph is exceedingly simple. Two type wheels, W, W′, Fig. 168, of the same size, are maintained in synchronous rotation by any suitable means, and are placed at the transmitting and receiving ends of a single telegraph wire connecting the two stations. Two electro-

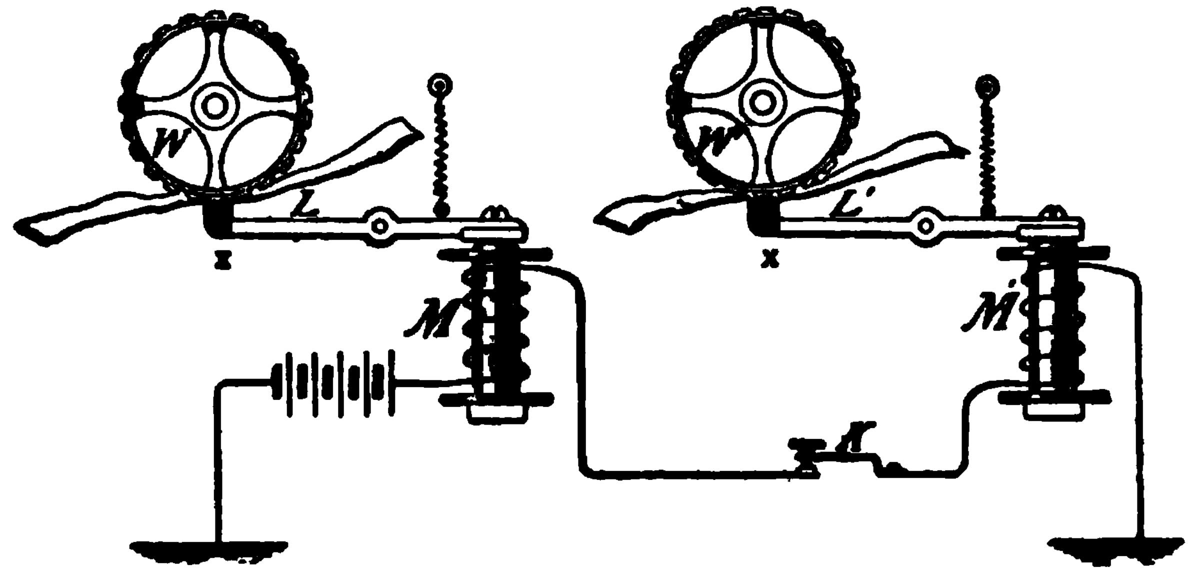


Fig. 168.—General Principle of the Step-by-Step Printing Telegraph.
(By permission of William Maver, Jr.)

magnets, M, M′, have their armatures connected to levers, L, L′, so placed that the free terminals of such levers, *x*, *x*, come directly opposite the lower part of the wheel, as shown. Suppose, now, the two printing wheels being synchronously rotated, and the letter a, being at the lowest extremity of each of the two wheels, an electric impulse be sent into the line by the depression of the key, K, and that, at the same time, the rotation of the two wheels be momentarily stopped. The passage of the electric impulse through the coils of the electro-magnets moves the armatures, and causes the ends of the levers, *x*, *x*, to press the fillets of paper against the type wheel, so that, these

wheels being kept inked, there will be printed on each of the paper fillets the letter a. If, now, synchronism be maintained, then at any moment the same letter will always be on those portions of the two type wheels that lie nearest to the paper fillets. If, therefore, the wheels be stopped at the proper time, and the paper fillet be pressed against the printing wheels, it is evident that the message will be received in printed characters on the fillet, arrangements being made that the paper fillet, after receiving any single letter, may be automatically advanced into a position in which it will be ready to receive the next printed letter. In actual practice, of course, a number of printing instruments are placed on the same line, the same printed message being received on each.

General operation of the step-by-step printing telegraph.

Though simple in theory, yet, in actual practice, it has been found very difficult to maintain the exact synchronism between the two type wheels that is necessary for the proper operation of the printing telegraph. It can readily be seen how unintelligible would be the message received if one of the wheels was only a single letter or character either back or ahead of the other. In order to avoid this, various plans have been proposed. The one most frequently adopted places the control of the type wheels at the various stations under the influence or control of a sending transmitter. The plan most generally adopted for this purpose employs the step-by-step movement obtained by the alternate to-and-fro movements of the armature of a polarized relay. These movements operate an escapement, which permits an escape wheel to rotate a single tooth or step for each impulse. If, therefore, the type wheel be provided with 36 separate teeth or type characters, and the transmitting operator desires to repeat the same letter, it will be necessary that he send into the line

wire 36 separate impulses, since this will cause the wheel to make 36 successive steps, and thus complete a single rotation; and so for any other character. In some forms of printing instruments, such, for example, as the stock ticker, the necessary number of separate impulses required to bring a type wheel step-by-step from the particular character at which it stands to the next character that is to be printed is obtained by means of the depression of a number of keys corresponding to the desired letters.

FIG. 169.—Callahan's Stock Ticker. Note the separate series of letters and of numerals on the record slip.

Callahan's stock ticker.

In some forms of stock tickers there are two separate type wheels placed on the same instrument. On one of these wheels are placed the letters of the alphabet, and on the other the numerals. The stock ticker represented in Fig. 169 was invented by Callahan. Here, as will be seen, two printing wheels or type wheels are placed side by side above a paper fillet. The two separate wheels are moved by suitable step-by-step devices, the necessary impulses being sent into the line by means of specially arranged circuit makers and breakers. When the proper let-

ter or numeral is reached at the distant end of the line the printing wheel is stopped, and the paper fillet is pressed against its surface.

Generally speaking, electric time telegraphy embraces all methods by which time is telegraphically transmitted over a line. It includes means whereby the true time is telegraphically announced, either to an entire neighborhood, or to a limited number of people, as well as the means by which a single and especially accurate timepiece, whose pendulum opens and closes an electric contact placed in a conducting line, is made to control the time of a number of separate watches or clocks by means of electro-magnets placed in the same circuit.

Electric time telegraphy.

The correct time may be telegraphically announced to an entire neighborhood by the dropping of a time ball. Such balls are dropped at the exact moment of noon at many of the principal ports of the United States. By observing these balls, navigators are able to ascertain whatever error may exist in their chronometers. A form of such a time ball is represented in Fig. 170. The ball is placed at the top of some tall building, and is dropped at the exact instant of noon by means of an electric current that is automatically sent into a circuit by the use of an especially exact timepiece. In order to check the accuracy of this timepiece, it is carefully compared with the standard clock at the National Observatory at Washington.

Electric time ball.

In addition to the above, the true time is telegraphically announced to various railway companies, watchmakers, and jewellers by means of certain prearranged signals, controlled by a standard clock. These signals consist either of the strokes of a Morse

Telegraphing time to railway companies, jewellers, and so forth

sounding instrument, or the taps of an electro-magnetic bell. In the system employed in New York City and its neighborhood, a standard clock transmits signals into a telegraph line at the rate of one for every two seconds, omitting one each minute at

FIG. 170.—Electric Time Ball for Telegraphically Announcing Correct Time to an Entire Neighborhood.

the 58th second; while again, at 20 seconds before the commencement of every five-minute period, the signals again cease.

Master or controlling clocks.

In another system of time telegraphy, a number of separate clocks are corrected or brought into time with an especially accurate standard clock, by means of correcting electric impulses sent over a line wire. These impulses are caused to synchronize the other

clocks by means of some electro-mechanical device, which moves the minute hand either backward or forward as is rendered necessary, these movements being determined by the character of the impulse.

Another form of time telegraphy consists in the use of a standard master clock for sending into a line

FIG. 171.—Controlling or Master Clock.

wire a number of separate electric impulses by the to-and-fro movements of its pendulum. Various methods are employed for establishing these contacts. In the arrangement represented in Fig. 171, as the pendulum of the standard or master clock moves to-and-fro, it makes and breaks contact, at S and S′,

Master and secondary clocks.

with a split battery, *n*, *p*, and in this way sends positive and negative impulses into the line. Another system, and one less apt to affect the time of the standard clock, is by the employment of a surface of mercury for such contacts.

FIG. 172.—Secondary Clock. Note the mechanism of the step-by-step movements.

Mechanism of secondary clocks.

There is employed, in connection with the master clock, a number of secondary clocks. These are of quite simple construction, being, in fact, only clock dials, containing step-by-step movements, by means of which the minute and second hands are moved over the dial. Such a secondary clock movement is represented in Fig. 172.

CHAPTER XXII

INDUCTION AND RAILROAD TELEGRAPHY

"I'll speak in a monstrous little voice."
—*A Midsummer-Night's Dream*, Act I, Scene I

IT was known, long before the general introduction of the speaking telephone, that, when the rapidly interrupted currents employed in systems of Morse telegraphy were transmitted through any of the overhead conducting lines or wires on the pole lines, there were set up by induction similar currents in all the neighboring wires. In this manner the inductive disturbance known as telegraphic cross-talk originated. It was not, however, until the general introduction of the speaking telephone, with its marvellously sensitive receiver, that it was known how great was the distance at which such inductive disturbances could produce intelligible signals when so delicate a receiver was employed for their reception. If a Bell telephone receiver be introduced into the circuit of any of the many wires on a pole line, through which no direct currents are passing, the effects of the disturbances produced by neighboring active wires will be found to be exceedingly marked. It is not necessary, however, that the disturbing wire be situated on the same pole line, since it has been shown that such inductive disturbances can be transmitted between wires several miles apart. Experiments of this character were undertaken by William H. Preece, now Sir William H. Preece, of England, on the town moor at Newcastle, when he found that

General nature of inductive disturbances on telephone lines.

the greatest distance at which he could conveniently separate the two wires, viz., a quarter of a mile, was by no means at the limit of their inductive influence. Later the same gentleman successfully transmitted messages inductively between Bristol and Gloucester, a distance of some 4½ miles. In all experiments of this kind, it is necessary that the inducing wire be placed, approximately, parallel to the wire on which it is desired to produce an inductive influence.

Some examples of distant inductive action.

In the early experiments on the distance through which an inductive influence could be produced by one wire on another, it was believed that evidence had been obtained of a much more extended area of disturbance than that just mentioned. For example, in some experiments that were conducted during the summer of 1886, it was thought that signalling had been successfully carried on by the inductive method across a distance of some 40 miles lying between the main telegraphic lines that extend along the eastern and the western coasts of the northern part of England. It was afterward shown, however, that this was not due to actual induction occurring through this distance of intervening air, but had taken place through the medium of the intricate network of telegraphs that extended in various directions across this part of the country. In some instances, effects ascribed solely to induction have been shown to be, to a greater or less extent, dependent also on conduction through the ground. It is now, however, generally recognized that induction through the air can take place through distances of several miles, and that this distance could probably be considerably extended under special circumstances.

The possibility of thus transmitting telegraphic messages across an intervening air space by means

of inductive effects, has been practically applied in the case of a system of inductive telegraphy between two moving railroad trains, or between a moving train and a station along the road at some distance from such train. There are several different ways in which this can be done. The one in most common use is that represented in Fig. 173. Here communication is readily established between a station connected with the telegraph wire, W, W, and a car that is either moving rapidly over a track alongside the telegraph wire or is standing still on said track. The metallic roof, R, R, of the railroad car, insulated from the body of the car by means of the wooden

Inductive telegraphy on railway trains.

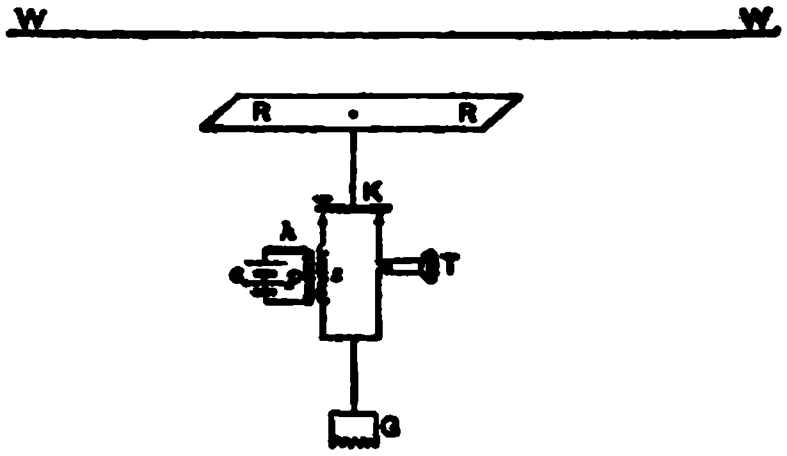


FIG. 173.—Inductive Telegraphy on Moving Railway Trains.

frame, is connected, as shown, with the key K, the back-stop of which is connected through the receiving telephone, T, to a ground at G, established by means of the contact of the car wheels with the tracks. The front stop of the key is connected with the secondary, *s*, of an induction coil, whose primary, *p*, is placed in the circuit of the voltaic battery, *e*.

Suppose, now, that the line wire, W, W, is connected with the secondary of an induction coil placed at one of the stations to which this line extends, so that a rapidly intermittent current is sent into it. These variations will, by induction, charge the circuit with which the roof is connected with feeble electric currents, so that any one listening in the telephone,

T, will be able to clearly distinguish such currents as a buzzing sound, of a pitch dependent on the rate at which the interruptions are produced. If, now, at the sending station, instead of permitting a continuous series of makes and breaks to enter the line from the induction coil, they are interrupted by means of a Morse key, in such a manner as to send characters corresponding to the dots and dashes of the Morse alphabet into the line, the operator listening at the telephone in the car will receive the message transmitted in the form of buzzing dots and dashes of the Morse alphabet. In the same manner, if the apparatus in the car be provided with an automatic make-and-break introduced into its primary circuit, then the charges produced on the metallic roof, R, R, of the car, connected with its secondary circuit, will induce charges in the line, W, W, distinguishable to a person listening at the telephone in any of the stations along the line as a continuous buzzing. Moreover, on the working of the key, K, in the car so as to send Morse characters into the circuit of the induction coil, the charges so produced on the roof will produce inductive disturbances that will enable them to be heard as buzzing dots and dashes at any of the stations along the line. In this manner, actual telegraphic communication has been established between a moving train and stations along the line for a distance as far as 50 miles. The reasons that such a system of inductive telegraphy has not been more generally employed on moving trains, are the matter of the expense of the additional operators, as well as the fact that the necessary messages can be sent to such trains more conveniently by handing the message to the conductor when the car passes the next telegraph station. It must be evident, however, that circumstances may readily arise in which it might be very

Operation of inductive telegraphy on railway trains.

Why inductive telegraphy is not generally employed.

important to stop a train after it has passed a station and before it reaches the next succeeding station, and that such stoppage of a train may result in the saving of expense far greater than that which would be required for damages resulting from a serious accident.

All important railroads are now provided with some system for securing safety from collision by dividing the road into a number of blocks or sections of a given length, and so maintaining telegraphic communication between such blocks as will prevent, under certain circumstances, more than a single train or engine to be on the same block at the same time. **Block system on railroads.** There are two distinct block systems; viz., the permissive and the absolute. In the permissive block system, more than a single train is permitted on a block under certain circumstances, each train being then notified that it is not the only train on that block. In the absolute block system, only a single train or engine is permitted to be on the same block at the same time.

In order to notify the conductor of a train as to the condition of the blocks, some system of semaphoric signals is employed. The semaphores are operated either mechanically, by means of metallic wires or ropes moved by levers by an operator in **Semaphoric signals.** a block tower, after he has obtained knowledge of the moving trains either by seeing them or by telegraphic communication, or the semaphores may be operated automatically by the train through the action of compressed air and electric currents.

A common form of semaphoric signal is represented in Fig. 174. Here the semaphore arm, A, B, consists of a light, movable wooden arm, capable of being set in either two or three positions, according to whether the absolute or the permissive block sys-

Semaphoric signals for "danger," "safety," and "caution."

tem is employed. When the semaphore arm is in a horizontal position, or that in which it makes an angle of 90° with the upright pole to which it is attached, it occupies what is known as a "danger" position, and when it is displayed the trains may not enter the block it governs. When the semaphore arm is dropped down from the horizontal position through an angle of 75°, it indicates a "safety" position, indicating that the line is clear, and the train

FIG. 174.—Semaphoric Signal Employed in Block System on Railroads. Note the positions of the semaphore arm for Danger, Caution, and Clear.

may safely enter the block it governs. In the permissive system, there is a third position; viz., a position intermediate between the danger and the safety positions. In this position the semaphore indicates "caution," and permits the train cautiously to enter the block, and look out for further signals.

Block systems may be either non-automatic or automatic. In the former case, the signals are oper-

ated by an observer placed in a signal tower at the end of each block. In the latter case, they are operated by the trains as they pass from one block to another. In all cases, however, some system of telegraphic communication must be established along the line, by means of which either the operator in charge of the signal towers may receive the instructions necessary to operate the semaphoric signals, or the trains themselves may be able to successively make and break a series of electric contacts placed alongside the road. Generally, even in automatic block signals, some method of telegraphic communication is necessary along the railroad.

Necessity for telegraph lines along railroads.

In the case of the block system employed on the Pennsylvania Railroad, between Philadelphia and Jersey City, three separate telegraphic wires are required for the following purposes; viz., wires, called train wires, employed for sending train orders only (these wires connect the block towers with the general despatcher's office at Jersey City); a block wire, connecting each block tower with the next tower on each side of it; and a line or message wire, employed for local business only.

In the automatic electric block system, as already indicated, the passage of the train into a block sets the danger signal. This signal is continued until the train leaves that block and enters the next block, when the danger signal is automatically lowered, and either the safety or the caution signal displayed, according to whether the absolute or the permissive block system is employed. In one form of automatic block system, the downward movement of the semaphore arm is obtained by means of compressed air acting against a counter-weight, the air pressure being governed by means of electro-magnets.

Automatic electric block system.

Another form of railroad safety appliance that depends for its operation on the movements of the armature of an electro-magnet, is the automatic signal for grade crossings. In this device, a gong or bell is automatically rung at the railroad crossing as soon as an approaching train crosses a certain part of the track, and continues sounding until after such train has passed the crossing. As soon as the train reaches a certain part of the track, a circuit is automatically completed through the coils of one electro-magnet, that, by the attraction of its armature, completes the circuit of another electro-magnet, that rings the gong or bell. The circuits are so arranged that the armature of the first electro-magnet remains attracted until the train has passed over the grade crossing. Consequently, the bell continues to ring or sound until this time. As soon, however, as the train has passed the crossing, the armature of the first electro-magnet is released as its circuit is opened automatically by the train, and, consequently, the bell ceases sounding.

Automatic electric signals for railroad grade crossings.

In some railroads, the ordinary bell-cord signals have been replaced by electrically operated signals, depending for their action on electro-magnetism. Such systems have been devised both on the open and closed-circuited plan. There are, however, many difficulties in maintaining the contacts, and in avoiding the sounding of false signals by accidental contacts, so that the old system of the bell-cord signals is still in very general use.

Bell-cord signals still in general use.

CHAPTER XXIII

WIRELESS OR SPACE TELEGRAPHY

"Canst thou send lightnings, that they may go and say unto hee, 'Here we are'?"—JOB. XXXVIII, 35

WIRELESS or space telegraphy, as the words indicate, is a system of telegraphy in which communication is established between two stations without the use of connecting wires or conductors. Instead of having the two stations between which it is desired to establish telegraphic communication, joined by conducting wires, it is only necessary to place transmitting apparatus at one station and receiving apparatus at the other station. At the transmitting station electro-magnetic waves are produced by means of disruptive electric discharges. These waves, moving outward in all directions through the luminiferous ether, come in some part of their path in the neighborhood of receiving apparatus, in which they produce certain effects by means of which the message is recorded. Such telegraphy is called wireless telegraphy, because communication can be established between two stations without the use of connecting wires. It is also called space telegraphy, because the impulses, transmitted from one station, pass through the space existing between the two stations.

Simple nature of wireless or space telegraphy.

In the early history of the art, it was feared that the curvature of the earth would prevent a system

certain parts of the ear into vibration, the pitch of the note heard depending on the number of such vibrations.

Now each string of a piano has practically only a single definite rate at which it can readily be set into vibration. Consequently, each string produces a note of a particular pitch. When a strong note is sung into the open piano, the sound waves strike all the strings, and give to each a slight push or forward movement. The amount of this movement, however, is far too small to enable the string to continue its to-and-fro motions and produce any appreciable sound. In the case, however, of some particular string whose time of vibration—that is, the time it would require to make a complete to-and-fro motion—is exactly the same as that of the time of vibration of the sound uttered into the piano, it follows that just as the string has completed its downward and upward motions, and is again ready to move downward, it will receive a second impulse from the sound waves in the same direction, thus adding to the amount of motion it has already acquired. Moreover, if these successive impulses are each received at exactly the time when the string has completed its upward movement and is ready again to move downward, the total motion set up in the string will soon be sufficiently great to cause it to emit an audible musical sound. It will not be so, however, with any of the other strings, unless, to a certain extent, with strings whose rates of vibration are in equal multiples of the rates of vibration of the sound waves; for, although all such strings will receive equally powerful impulses, yet such impulses will not be timed, but will frequently act to move the string in the opposite direction to that in which it has already been moved, and would,

How timed impulses are able to add their effects.

ELECTRICITY IN THE KITCHEN

The upper picture shows an electric cooking outfit—oven, broilers, etc. The oven may be maintained at "high," "low," or "medium" heat. The lower picture is a dishwashing machine, operated by an electric motor

therefore, tend to take from rather than add to the amount of its motion.

As we shall soon see, the receiving apparatus employed in certain types of wireless or space telegraphy depends for its operation on sympathetic vibrations set up by the electro-magnetic waves that are caused to travel through the ether in all directions from the transmitting instrument. The general principle of sympathetic action is the same, whether the vibratory movements in the ether take place at the rate of hundreds of millions of vibrations per second, or whether they take place in the air at the rate of a few hundreds of vibrations per second. Sympathetic vibrations will only be set up in such receiving instruments as are tuned to certain definite rates of vibration. Consequently, although there may be speeding through the ether surrounding the earth waves produced by thousands of wireless telegraphic transmitters, yet to a certain extent such waves may pass by any receiver which is not tuned so as exactly to agree or be in sympathy with a particular transmitter, just as if such waves were not present. It is this possibility of tuning the receiving instruments employed in wireless or space telegraphy, so that they will respond only to the waves produced by some particular transmitter, that ensures the privacy of the messages sent bv wireless telegraphy.

Effort to ensure the privacy of wireless communications.

Since it is the universal ether that conveys the electro-magnetic waves in wireless or space telegraphy, it is not, in a general sense, true that each pair of correspondents is furnished with a distinct and separate line, pre-empted in the ether. On the contrary, all other correspondents who are sending or receiving messages by this kind of telegraphy

A single, huge ether conductor for all wireless correspondence.

are connected together in multiple to a single huge common conductor, *i.e* with the ether itself. Into this universal medium there is being sent from every transmitting instrument that is employed in wireless telegraphy, the peculiar waves or vibrations which have been selected for the use of each set of apparatus. All of these vibrations impart their peculiar character to the surrounding ether, so that there is thus set up in the ether a series of exceedingly complex waves, that practically affect the entire mass of the ether over very extensive regions. When such a complex wave comes into the neighborhood of a wireless telegraphic receiver, this receiver is not affected unless there is present in the complex wave the peculiar rate of vibration to which this especial receiver is tuned. All other waves pass by it as if it had no existence.

Possibility of intercepting wireless messages.

Of course, if, by some mischance, more than a single set of correspondents happen to have selected the same rate of vibration for their transmitting instrument, then both sets of correspondents will receive indifferently the messages that are only intended for one of them. Consequently, although it is unquestionably a great convenience to be able to readily convey intelligence between any two points on the surface of the earth without being obliged to connect such points by conducting wires, yet such convenience is subject to the disadvantage that the ether between such points is at the same time open for the use of all others who desire to employ it. Unless the transmitting and receiving instruments are carefully tuned by each selecting some peculiar rate of vibration, so that no other instruments are likely to adopt the same rate of vibration, then the messages conveyed by wireless telegraphy are open to the great objection of being possibly read by

others than those for whom they have been designed. It will be interesting, therefore, to inquire at some length as to the general character of the vibrations or waves that are likely to be present in the ether at any place.

A very little thought will show that such vibrations are of an extremely varying character. The universal ether is practically never at rest, but is continually throbbing with vibrations that differ markedly in length; for, as is well known, this ether is the medium through which heat, light, and all other electro-magnetic disturbances are propagated. Moreover, it is now generally recognized that the electro-magnetic waves which are sent off in all directions through space by the discharge of a Leyden jar, induction coil, or other disruptive discharge, differ from the waves that transmit light and heat only in their wave length. The following varieties of electro-magnetic waves are, therefore, probably always present in the universal ether; viz., the electro-magnetic waves from the sun, produced by an unusual disturbance in its magnetic equilibrium. These may be of exceedingly great wave lengths, possibly, in some cases, amounting to more than one million of miles for each wave, or waves whose numbers of vibration would possibly be about one in every 6½ seconds; the electro-magnetic waves produced by the lightning flash are much shorter, being estimated at something like 11,000 miles in length, or somewhere in the neighborhood of 17 per second. Coming to the electro-magnetic waves produced by man, according to A. V. Abbott, induction coils can be made producing waves 18 miles in length, or some 10,000 vibrations per second. The waves produced by a pint Leyden jar are 54 feet long, or 18,000,000 vibrations per second. A

Great variety and range of ether vibrations.

Varying wave-lengths of electro-magnetic waves.

large oscillator may produce electro-magnetic waves one foot in length, or 1,000,000,000 vibrations per second; a five-inch oscillator may produce waves 7 inches long, or 1,720,000,000 vibrations per second, while the shortest electrical wave is estimated at 2½ inches in length, or 4,800,000,000 vibrations per second.

Electro-magnetic heat waves.

The electro-magnetic waves that transmit the effect which is generally recognized as heat are much shorter, varying from 20 trillions of vibrations per second for the lowest heat sensation, to 300 trillions of vibrations per second for the highest heat sensation, while those required to produce light are still shorter, varying from 434 trillions of vibrations per second for red light, to 740 trillions per second for violet light, while the radiations beyond the violet are produced by vibrations reaching the enormous number of 870 to 1,500 trillions of vibrations per second.

Wide possible range of electro-magnetic waves in the ether.

The existence, therefore, is possible in the universal ether of waves varying from 1¼ millions of miles in length to the $\frac{86}{10,000,000}$ of an inch in length, which, as will be seen, is an exceedingly great limit. There is, consequently, an extremely wide range in which possible electro-magnetic waves can be set up. Although only those within certain comparatively limited ranges of vibrations can be employed in wireless telegraphy, yet such range is, in point of fact, extremely great. It is possible, therefore, for a great number of different receiving instruments to be employed, all of which shall have a distinctive and peculiar electro-magnetic tone. In other words, it is possible for a great number of receiving instruments to be employed that shall be entirely independent of one another. Let us now look more closely into the

methods actually employed in wireless or space telegraphy, at the same time briefly tracing the early history of this important branch of the electric art.

Strictly speaking, wireless or space telegraphy was first actually carried into practice in the case of the inductive telegraphy to which we have referred in the last chapter. Here electric currents that rapidly alternate or change their direction are caused to flow through one conductor or wire, and produce by electro-magnetic induction waves in neighboring conductors or wires. Moreover, such a system of inductive telegraphy has been actually employed, although in only a limited manner, on some of the

Inductive telegraphy a specie of wireless or space telegraphy.

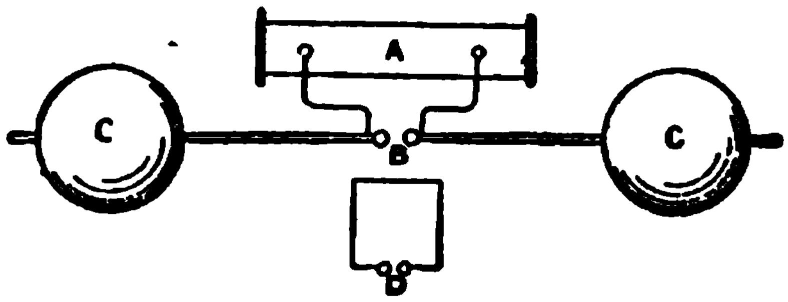


Fig. 175.—Hertzian Oscillator for Producing Electro-magnetic Waves. Note the connection of the secondary terminals with the brass rods and their regulable spark gap.

railroad lines in the United States; and if it has not been more extensively introduced on such lines, it has not been by reason of any inherent difficulties, but apparently only on the score of imaginary economy. But, leaving such systems of wireless telegraphy out of the question, and using these words only in the now commonly accepted sense, the first actual establishment of wireless telegraphic communication was that of Prof. A. Popoff, of the Cronstadt Torpedo School, who presented, in April, 1895, to the Russian Physical Society, the system of wireless telegraphy represented in Figs. 175 and 176.

Popoff's wireless telegraphic system.

The transmitting instrument shown in Fig. 175 consists of a Hertzian oscillator, by means of which

electro-magnetic waves are produced. The oscillator consists of an induction coil, A, the secondary terminals of which are connected to a pair of brass rods, terminated at their approached ends in two highly polished knobs, B, adjustable as regards the distance between them at B. The brass rods bear two large metallic spheres, C, C, that slide on the rods so as to permit the distance from the two balls at B to be readily varied. When a disruptive discharge takes place between the balls at B, electro-magnetic waves are propagated in all directions

Hertz oscillator.

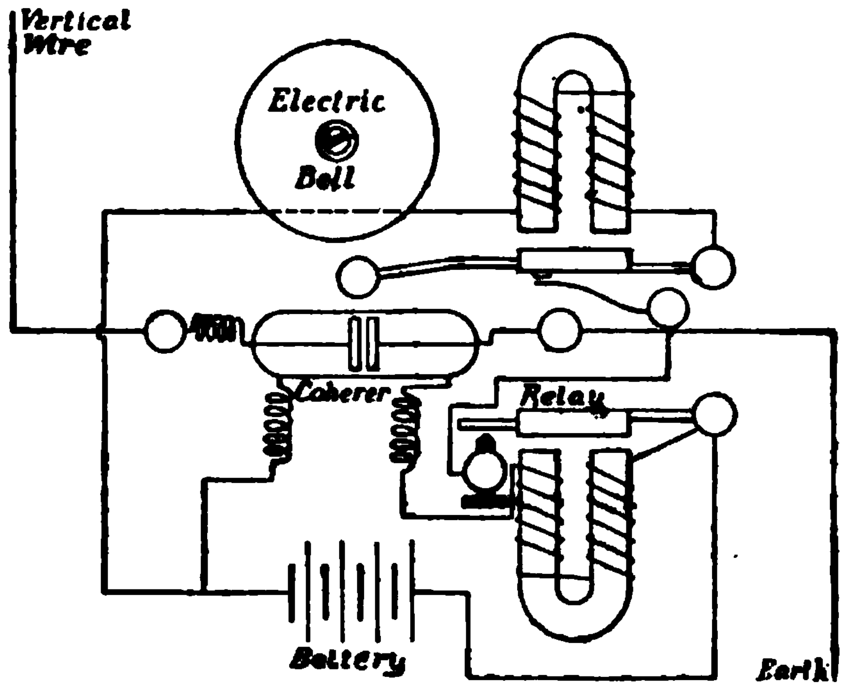


FIG. 176.—Popoff Receiving Apparatus for Wireless Telegraphy.

through space. If such disturbances are sent into space at rates corresponding to the dots and dashes of the Morse telegraphic alphabet, and the transmitting instrument is tuned in accordance with a receiver, waves will affect such receiving instrument in a manner we will now briefly describe.

The receiving instrument of Popoff consists of a vertical wire or exploring rod, Fig. 176, that is connected to the earth through an instrument called a coherer, which, in its turn, is connected with the circuit of a voltaic battery and an ordinary telegraphic

relay. This relay was caused to close the circuit of another and larger battery, not shown in the figure, in whose circuit was placed an electro-magnetic bell, and a telegraphic recorder. The coherer consists of a glass tube partly filled with metallic filings. Under ordinary circumstances, the electric resistance of these filings is so great that the battery current is not completed through them. When, however, an electro-magnetic wave of a definite rate falls on the coherer, an effect is produced on the filings which causes them to cling more closely together, or to cohere, so that their electric resistance falls from an almost infinitely high value to a value of perhaps only 500 or 1,000 ohms. Consequently, the current from the battery flows through the coherer, and the relay, being actuated, closes the circuit of the larger battery, actuates the recorder, and leaves a permanent record of the impulse so received. At the same time, however, the electro-magnetic bell gives the coherer tube a short, quick blow or tap, and thus causes the filings to decohere, or to fall apart, thus breaking the circuit of the coherer, and, consequently, of both batteries.

General action of the Popoff apparatus.

Concerning the above apparatus, Popoff said, in December, 1895: "I entertain the hope that when my apparatus is perfected it will be applicable to the transmission of signals to a distance by means of rapid electric vibrations."

The essential parts of a system of wireless telegraphy may, therefore, be regarded as consisting of the following; viz., first, the transmitter by means of which electro-magnetic waves are propagated in practically all directions; second, of the coherer. Let us now go, at some little detail, into the history of these two parts of the system of wireless telegraphy.

Essential parts of a wireless system.

The discovery that electro-magnetic waves are produced by disruptive discharges dates back as far as 1838, when Prof. Joseph Henry was carrying on his researches in mutual and self-induction. At this early day, Henry pointed out his belief that such discharges were oscillatory in character. In 1886, Hertz began his magnificent series of researches on electric waves, when he made the important discovery that, in order to produce electro-magnetic disturbances in insulated spirals or coils of wire, it was not necessary to use the discharges of powerful batteries, but that such discharges could be replaced by the discharges of Leyden jars, provided the Leyden-jar discharge was made to take place through a small air space. Several years before the time of Hertz's experiment, Prof. Oliver Lodge, of England, was conducting the series of experiments to which we have already called attention concerning the manner in which lightning-rods act. In these investigations, Lodge nearly anticipated Hertz concerning the actual existence of electro-magnetic waves. In some of his experiments, Lodge placed two small Leyden jars about two yards apart, and succeeded in charging one of the jars by the discharge of the other, although there was no connection between them whereby charges might have been produced conductively. In order to obtain these results, Lodge found that it was necessary to tune the two jars. This he did as follows: Selecting two jars that were as nearly alike in size, general character, etc., as possible, he connected the jar at B with an ordinary electro-static induction machine, as represented in Fig. 177, and provided a circuit about one yard in diameter, connecting the inner and outer coatings of the jar, and provided with a short air gap at C, where there were two highly polished metallic balls. A second jar, placed at a distance of about two yards

Henry's researches.

Experiments of Professor Oliver Lodge.

Lodge's experiments with tuned Leyden jars

from the first, was provided with a metallic slider, D, which was capable of adjustment until the two jars were tuned, the fact of this tuning being determined by moving the slider until the discharge between the balls at C caused a discharge to take place in A, at E′, by means of a thin strip of tin-foil that had been placed over the upper edge of the jar, so as to bring the inner coating a short distance from the outer coating. Lodge called this process of causing one jar to have its dimensions so varied as to make it readily influenced by the other jar, syntonizing, or tuning the jars.

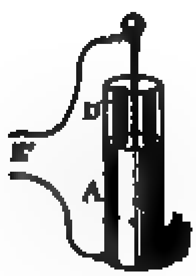


FIG. 177.—Lodge's Syntonic or Tuned Leyden Jars.

In a piano, the number of vibrations per second a string produces depends on the force with which the string is stretched, as well as on its size, that is, its length and thickness, and on its density. In the case of a Leyden jar, the number of vibrations that the discharge will set up in the space around it depends on the capacity of the circuit connected with the jar, or on the value of the electric charge the jar is capable of holding. This capacity corresponds to the flexibility of the wire, so that, within certain limits, the number of vibrations the discharge pro-

How the capacity of a Leyden jar affects its rate of vibration.

duces may be varied by varying the capacity of the jar. In a similar manner, the inertia of the piano wire corresponds to the self-induction of the electric circuit connected with the Leyden jar. Any cause which increases either the capacity or the self-induction will decrease the rate of vibration or oscillation, so that, if the size of the Leyden jar be increased, or the length of the circuit connected with it be increased, the number of vibrations per second will be decreased; or, in other words, the length of the waves will be increased.

Oscillations of Leyden jar momentary.

In the case of a piano wire, the vibrations will continue for a comparatively long time, provided the wire be free to move, but will rapidly die away if the wire be damped by the pedal, or by surrounding the wire with some viscid substance like oil. Now the oscillations of a Leyden jar do not continue for a very long time, but rapidly die out. They may, however, be damped still further by introducing a resistance into the circuit of the discharge.

Resemblances of Hertz's oscillator to Lodge's Leyden jars.

Hertz's oscillator was in reality a Leyden jar. It differed, however, from the Leyden jar of Lodge, in that it was of such a design as permitted a far more ready transfer of electro-magnetic energy to the surrounding ether. In the case of the Hertz oscillator, by varying the positions of the spheres C, C, on the brass rods, the oscillator could be tuned into sympathy with the receiving device Hertz employed, and called by him a resonator. This resonator consisted of a rectangular or circular wire, D, Fig. 175, that terminated in two highly polished balls, placed close together. It can be shown that, when the two coatings of a Leyden jar are placed near together, as in the Lodge syntonized jars, the waves given off by the disruptive discharge will have

a much larger proportion of magnetic energy than electro-static energy, and that, when the coatings are separated at a greater distance from each other, as in the Hertz oscillator, the two varieties of energy are more nearly equal, this being the condition in which the greatest amount of radiation will take place.

Coming now to the most important part of the receiving apparatus, viz., the coherer, we find that this part of the invention was one in which quite a number of different investigators had a part. Professor Lodge has published in the London "Electrician," for November 12, 1897, an excellent historical sketch of the discoveries that finally led up to the coherer. We shall avail ourselves of many of the facts cited in this article.

Lodge on the evolution of the coherer.

According to Lodge, the first observation of the fact that a disruptive discharge is able to produce the coherence of finely divided matter was made by Guitard, in 1850. Guitard's observation was the fact to which we have already alluded in Volume I., that when a discharge from a fine metallic point, *i.e.* a convective discharge, is passed through dusty or smoky air, a rapid clearing of the air results, the dust particles being deposited on the walls of the containing vessel. This clearing arises from the tendency of the dust particles, under the influence of the electric discharge, to cohere into strings or flakes.

Guitard in 1850.

In 1866, S. A. Varley described a form of lightning arrester, whose operation depends on the decrease in the electric resistance of a heap of dust particles by the passage of a discharge through them.

Varley, 1866.

We have already alluded, in Volume I., to the observation of Lord Rayleigh, in 1879, of the marked change produced in the appearance of a jet of water

Rayleigh, 1879.

by the approach of an electrified rod. Under these circumstances, the drops, instead of being scattered, collect together in larger drops. This was a case in which finely divided particles are caused to cohere under the influence of electric discharges.

Lodge and Clark on dust phenomena.

While engaged in experiments as to the cause of the freedom from dust of air in the neighborhood of heated bodies, Professor Lodge, in connection with J. W. Clark, rediscovered the electric dust phenomena of Guitard, and showed that such freedom was due to a molecular bombardment referred to by us in the previous volume in connection with the Crookes radiometer.

In 1889, while experimenting in connection with a modified form of saw-toothed lightning arrester employed for protecting telegraphic instruments, in which the approached teeth were replaced by two metallic balls, Lodge observed that when these balls were placed near each other, the simple discharge of a spark between them was sufficient to bridge the gap, even if it was only a spark produced by a small Leyden jar. He noticed, moreover, that when this gap was once thus bridged, a permanent contact was produced, as was proved by placing an electric bell and a small voltaic battery in the circuit of the contact. As soon as the spark passed, contact was established, and the bell continued to ring until the table on which it was placed was given a slight jar or tap, so as to mechanically break the contact.

Minchin, 1891.

In 1891, Minchin, while experimenting with a variety of photo-electric cell already referred to, and called an impulsion cell, observed that one of these cells was automatically connected to the circuit of an electrometer, whenever sparks passed across a

spark gap of a Hertz oscillator working in an adjoining room. Here, again, was the principle of the coherer, and Minchin actually succeeded in signalling through a distance of a few yards in this manner. It is interesting in this connection to note that the decrease in the electric resistance of selenium by light, *i.e.* electro-magnetic waves, may possibly be a phenomenon allied to the decrease in the resistance of the coherer on the falling on it of the larger electro-magnetic waves employed in wireless telegraphy.

Passing over some experiments made by Boltzmann with a charged gold-leaf electroscope, whose leaves were placed so as to be just on the point of discharging across a small air gap, and which was found to be very sensitive to Hertz waves, as well as some modifications of this experiment, by Lodge, who employed a carbon air gap, we come to the very important researches of Branley, who produced the particular form of coherer that is employed today in systems of wireless telegraphy. As soon as Lodge became acquainted with Branley's form of coherer, he produced, in connection with Fitzgerald, a coherer consisting of an ordinary sewing needle, resting on a strip of aluminium foil. It was during this series of experiments that Lodge made the great improvement in coherers by enclosing the same in a vacuum tube, or in an atmosphere of hydrogen, in order to ensure the continued working of the coherer by preventing any oxidation that might otherwise occur.

Branley's coherer.

Lodge's and Fitzgerald's microphonic contact coherer.

Having now briefly examined into the history of the art, we come to the form of wireless telegraphic apparatus devised by Marconi, shortly after the announcement by Popoff of his system of wireless telegraphy. Marconi made an application for pro-

Marconi's wireless telegraphic apparatus.

visional protection for a system of wireless transmission in June, 1896, and filed the completed specification for the same on March 2, 1897.

Marconi's long-distance transmitting apparatus.

Marconi's early apparatus are represented in Figs. 178 and 179, the first of which figures shows the arrangement of the transmitting apparatus, and the other figure that of the receiving apparatus. A marked resemblance will be observed between the apparatus of Popoff and Marconi, though, doubtless,

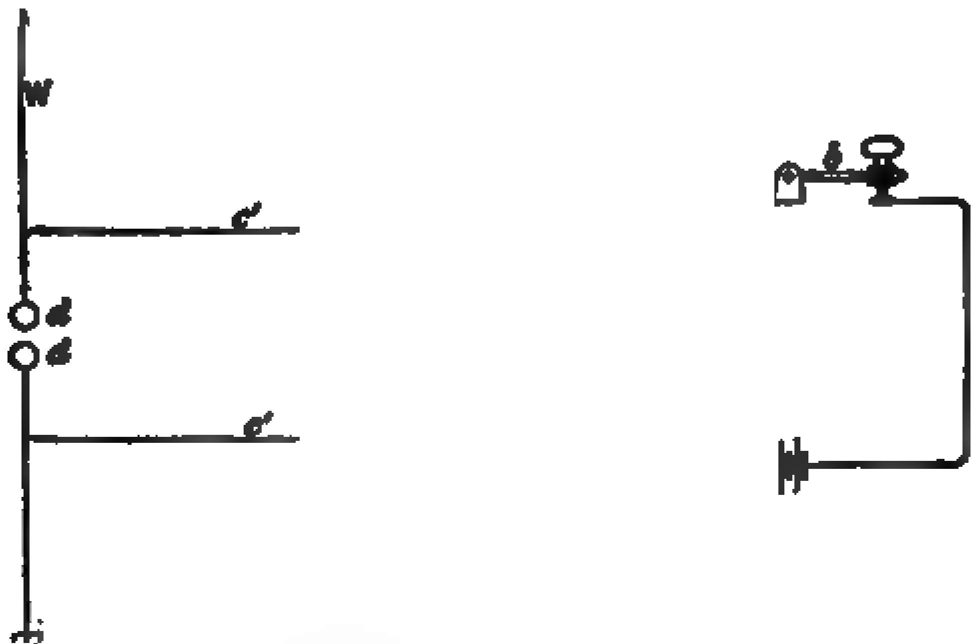


Fig. 178.—Long-distance Marconi Transmitter.

the latter individual was ignorant of what Popoff had already accomplished. In Marconi's transmitting apparatus, the induction coil, *c*, Fig. 178, has its secondary terminal connected by means of wires, *c'*, *c'*, to two small spheres, *d*, *d*, between which the sparks were passed. One of these spheres was connected with the vertical conductor, W, extending upward for some distance into the air, while the other sphere was connected to the ground by another wire as shown. A Morse key, *b*, was included in the circuit of a voltaic battery, *a*, and the primary of the induction coil, *c*.

In one form of Marconi's receiving instruments, the coherer tube is shown at j, j^3, Fig. 179. This coherer consists of two pole pieces of silver, j^1, j^2, placed at about the distance of $\frac{1}{25}$ of an inch apart, the gap between them being then partly filled by a mixture of filings of pure nickel, to which 4 per cent of silver filings had been added. A slight trace of mercury was mixed with the filings, since this has been found to greatly increase the sensitiveness of the instrument. After the filings are introduced, a moderately high vacuum is produced in the tube, which

Marconi's wireless telegraphic receiving apparatus.

FIG. 179.—Marconi Receiving Instrument with Vertical Exploring Wire and Earth-connected Conductor.

is then hermetically sealed. As in the case of the Popoff receiver, the coherer is placed in the circuit of a single voltaic cell, *g*, and a very sensitive telegraphic relay, *n*. The contact points of this relay are included in the circuit of a second and larger battery, *r*, in whose circuit is placed the telegraphic recording apparatus, *h*, and a trembling electro-magnetic bell, *pp*, as in the Popoff apparatus. The operation of the receiving apparatus is the same as in the Popoff system. When, by the action of electromagnetic waves the resistance of the coherer is decreased, the closing of the circuit of the cell, *g*, actu-

ates the relay. This closes the circuit of the larger battery, *r*, when two things happen; viz., a record of the impulse received is made on the recording apparatus, and at the same time the coherer is gently tapped by the electro-magnetic bell, so as to be caused to decohere, and thus be ready for the next electro-magnetic signal that might affect it.

Credit due to Marconi for wireless telegraphic system.

Although the Marconi apparatus was, in many respects, quite similar to that of Popoff, yet Marconi is to be credited with a large part of the advance that has been made in the art of wireless telegraphy. Marconi was the first to recognize the importance of the tall vertical wire at both the transmitting and the receiving station, whereas Popoff had employed it only at the receiving station. Moreover, Marconi introduced other improvements into the new art.

Use of choking coils

It will be noticed in Fig. 179, of the Marconi receiving apparatus, that choking coils, *k*, *k'*, are placed in the circuit between the coherer and the relay, for the purpose of causing the electro-magnetic waves to pass through the filings of the coherer, and not to expend a part of their energy in passing through the other or alternative circuit. Choking coils are also interposed between the recording instrument and the receiver terminals.

Use of a parabolic reflector.

In order to prevent electro-magnetic waves from passing in all directions through space around a transmitter, Marconi employs the transmitter devised by Righi, represented in Fig. 180. Here two large spheres, *e*, *e*, are placed between the smaller spheres, *d*, *d*, in the focal line of a parabolic cylindrical reflector. When such a reflector is employed as a receiver in order to determine the direction from which the signals are being received, the coherer is

placed in its focus, and the vertical wires, connected respectively to the ground and projecting upward into the air from the back of the transmitter, are disconnected, and replaced by two copper strips, attached to the terminals of the coherer. By altering the length of these copper strips, the receiver is tuned to the particular rate of electro-magnetic vibration of the transmitter. This form of reflector has not been practically employed but for comparatively short distances of a mile or two miles.

FIG. 180.—Marconi Long-distance Transmitter with Parabolic Reflector.

Efforts at tuning transmitting and receiving instruments

Much has been accomplished in order to obtain syntony between the transmitting and the receiving instruments, but it must be acknowledged that much still remains to be done in order to prevent the interception of messages. No little difficulty has been experienced, for example, in the English Channel and in other similar localities, where considerable signalling by wireless telegraphic systems is being carried on, in order to prevent the messages from being intercepted. A case is on record, during some naval manœuvres in the British Navy, where an English Admiral succeeded in intercepting the wireless messages sent by his rival. Various forms of apparatus have been devised for readily varying the rate of vibration both of the transmitting and the receiving instruments, so as to bring them into strict syntony. A form of syntonic transmitter is represented on the left-hand side of Fig. 181, in which

the vertical wires or antennæ, as they are sometimes called, are replaced by a pair of concentric conductors, A, A′, the central conductor being connected to the ground. A Morse key, *b*, and battery, *a*, is placed in the primary circuit of a transformer, whose secondary circuit, *c*, is connected, as shown, across the terminals of the spark gap, and in series with an inductive resistance, g^3. It will be observed that the outside and inside conductors, A, A′, are connected with the terminals of this circuit. Under these circumstances, the rate of vibration of the transmitting apparatus can be varied, so that it can be made to have a definite rate of vibration, such as shall possibly be possessed by no other transmitting instrument.

Antennæ replaced by concentric cylinders.

Method of tuning receiving apparatus.

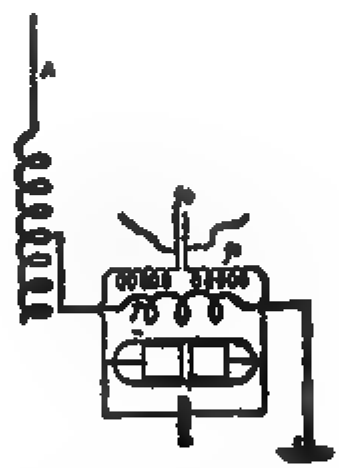


FIG. 181.—Marconi Syntonic Transmitting and Receiving Apparatus.

Various forms of syntonized receivers are also employed. The form represented on the right-hand side of Fig. 181 is so arranged as readily to vary the inductance of the vertical wire, A, by the use of the sliding wire represented. Here the coherer is placed in the circuit of the secondary, j^2, of the transformer, and in parallel with an adjustable condenser, *h*. The free ends of the secondary circuit are connected with the terminals, j^3, so arranged that

any desired inductance and capacity can be readily introduced.

It is an interesting fact that, in some of his early experiments, Marconi nearly failed from a lack of proper tuning between the transmitting and the receiving instruments. During some experiments tried in May, 1897, across a part of the Bristol Channel, the instruments failed utterly to respond for several days, and it looked as if the system was worthless. At last, when the experimenter was nearly ready to abandon his investigations, the receiving apparatus was taken from the top of the cliff, on which it had previously been placed, to the bottom, and connected by an additional length of wire of 20 yards, thus making in all 50 yards of vertical wire. The results were magical. Instantly the receiving instrument began to record, and signals came in a clear and intelligent manner. The addition of a few yards apparently tuned both instruments. Professor Slaby, of Charlottensburg, who assisted in these experiments, thus remarks concerning this incident:

Almost failure, but—

"It will be for me," he says, "an ineffaceable recollection. Five of us stood round the apparatus in a wooden shed as a shelter from the gale, with eyes and ears directed toward the instruments with an attention which was almost painful, and waited for the hoisting of a flag, which was the signal that all was ready. Instantaneously we heard the first *tic tac, tic tac,* and saw the Morse instrument print the signals which came to us silently and invisibly from the island rock, whose contour was scarcely visible to the naked eye—came to us dancing on that unknown and mysterious agent, the ether!"

Slaby of Charlottensburg.

The transmitting and receiving apparatus employed in these experiments are represented in Fig.

Marconi's transmitting and receiving instrument.

182. They are practically the same as those already represented. The signals are sent into the line by means of the key, K. These currents induced currents in the secondary wire, B, of the Ruhmkorff coil, so that spark discharges were sent between the balls 1, 2, and 3, and at *x*, out into the surrounding space. These waves, reaching *y*, were carried by the

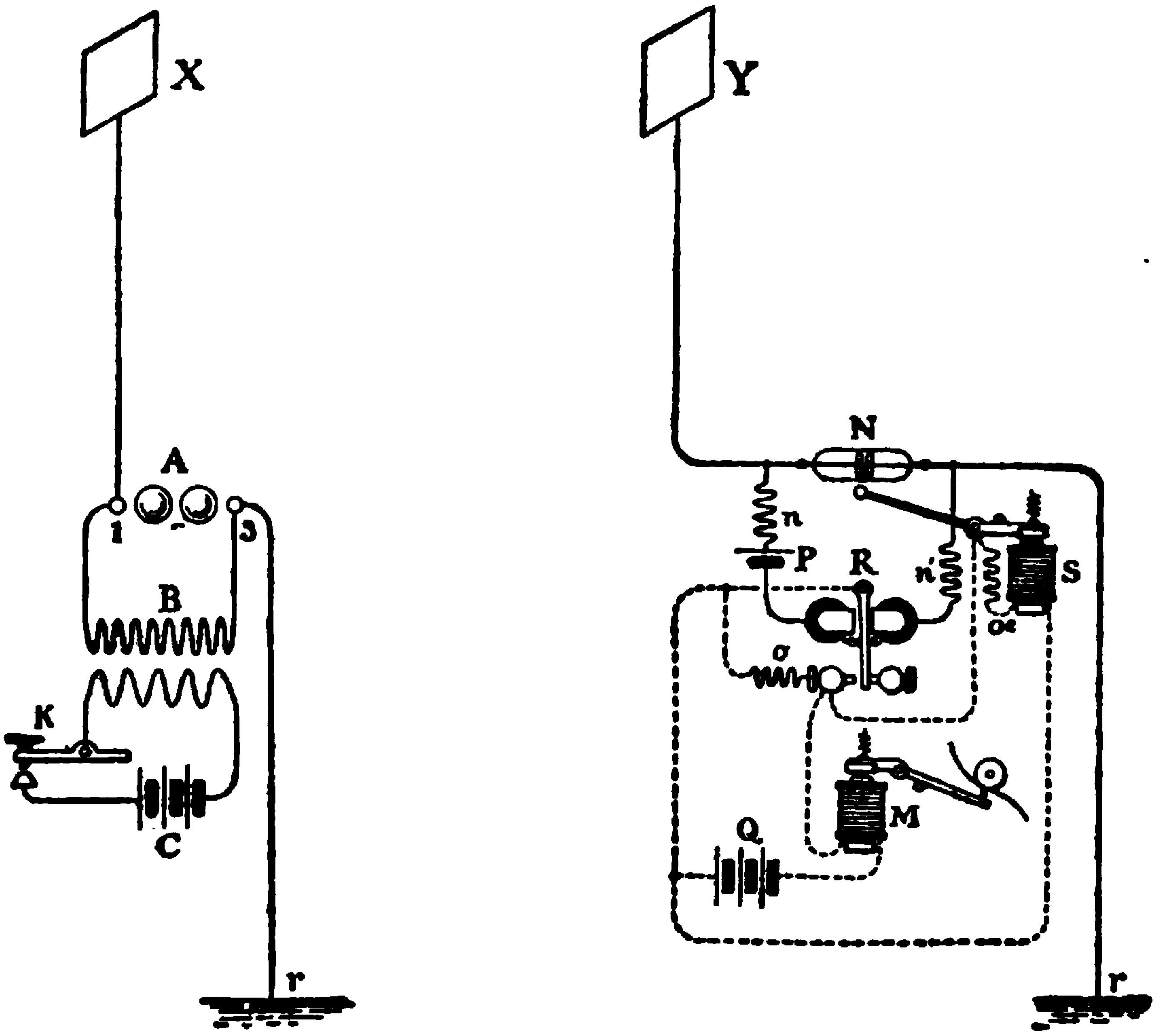


FIG. 182.—Transmitting and Receiving Instruments of Marconi.

conducting wire to the coherer, N, thus permitting the local battery, P, to close the relay, R, which introduces the battery, Q, connected with the recording instrument.

Much has been done in order to prevent wireless messages from being intercepted, but even if this could not be accomplished, the system of wireless

telegraphy would undoubtedly prove of great value to the world. So much, however, has already been done, that there would appear to be no reason for believing that improvements will not be made in the art, that wireless messages, when so desired, can be transmitted with absolute secrecy.

Value of wireless telegraphy even if capable of being intercepted.

Marconi had so far improved his system that, on the 27th of March, 1899, he had established wireless telegraphic communication between England and France, between a transmitting station at South Foreland, on the English side of the Channel, and a station near Boulogne. He employed for this purpose a ten-inch induction coil, by means of which he caused sparks to pass through a spark gap of about ¾ of an inch in length. The pole supporting the elevated antennæ, or air wires, was 150 feet high. The messages were transmitted at the rate of about 15 words a minute. Naturally, these experiments attracted considerable attention, and were very favorably received both by the scientific and the commercial world. J. A. Fleming, the well-known electrician of the University College, London, wrote a letter to the Editor of the London "Times," on April 3, 1899, from which we take the following interesting abstract:

Wireless despatch across the English Channel.

"During the last few days I have been permitted to make a close examination of the apparatus and methods being employed by Signor Marconi in his remarkable telegraphic experiments between South Foreland and Boulogne, and at the South Foreland lighthouse have been allowed by the inventor to make experiments and transmit messages from the station there established both to France and to the lightship on the Goodwin Sands, which is equipped for sending and receiving ether wave signals. Throughout the period of my visit, messages, sig-

Fleming on Marconi's results.

nals, congratulations, and jokes were freely exchanged between the operators sitting on either side of the Channel, and automatically printed down in telegraphic code signals on the ordinary paper slip at the rate of twelve to eighteen words a minute. Not once was there the slightest difficulty or delay in obtaining an instant reply to a signal sent. No familiarity with the subject removes the feeling of vague wonder with which one sees a telegraphic instrument, merely connected with a length of 150 feet of copper wire, run up the side of a flagstaff, begin to draw its message out of space and print down in dot and dash on the paper tape the intelligence ferried across thirty miles of water by the mysterious ether. . . .

Natural feeling of surprise.

"I can not help thinking that the time has arrived for a little more generous appreciation by his scientific contemporaries of the fact that Signor Marconi has by minute attention to detail, and by the important addition of the long vertical air wire, translated one method of space telegraphy out of the region of uncertain delicate laboratory experiments and placed it on the same footing as regards certainty of action and ease of manipulation, so far as the present results show, as any of the other methods of electric communication employing a continuous wire between the two places. This is no small achievement. The apparatus, moreover, is ridiculously simple and not costly. With the exception of the flagstaff and 150 feet of vertical wire at each end, he can place on a small kitchen table the appliances, costing not more than £100 in all, for communicating across thirty or even a hundred miles of channel. . . .

Simplicity of wireless telegraphic apparatus.

"In the presence of the enormous practical importance of this feat alone, and of the certainty with which communication can now be established between ship and shore without costly cable or wire,

the scientific criticisms which have been launched by other inventors against Signor Marconi's methods have failed altogether in their appreciation of the practical significance of the results he has brought about.

"The public, however, are not in the least interested in learning the exact meed of merit to be apportioned to various investigators in the upbuilding of this result. They do, however, want to know whether the new method of communication across the Channel, established by the expenditure of a few hundred pounds, will take the place to any considerable extent of submarine cables which have cost many thousands of pounds to lay and equip. They do also desire to learn what reasons, if any, will prevent every lighthouse and lightship round our coasts from being forthwith furnished with the necessary apparatus for placing it in instantaneous and secure connection with the mainland. They also hope to hear that the methods can be applied to enable ships to be able in addition to communicate instantly, in case of need, with shore stations. To understand how far these things can be done, and to appreciate the necessary or present limitations of the method, it is requisite to explain that each vertical wire or rod connected to a Marconi receiving or sending apparatus has a certain 'sphere of influence.' Signor Marconi has proved by experiment up to certain limits that the distance to which effective signalling extends varies as the square of the height of the rod. A wire 20 feet high carries the effective signal one mile, 40 feet high four miles, 80 feet high sixteen miles, and so on. Up to the present time he has not yet discovered any method of shielding any particular rod so as to render it responsive only to signals coming from one station, and not from all others within its sphere of influence. In spite, however, of what has

What especially interests the public.

been said, there is no inherent impossibility in attaining this desired result. At present all signals sent from the South Foreland to France affect the receiver on board the Goodwin lightship. But this offers no difficulty. In an ordinary electric-bell system in a hotel, the servant recognizes the room from which the signal comes by means of a simple apparatus called an indicator, and a very similar arrangement can be applied to distinguish the origin of an ether wave signal when several instruments are at work in a common region. Subsequent inventions, as also, perhaps, the promulgation of some necessary Board of Trade regulations for the use of the ether, will prevent official ether-wave receivers from being disturbed by vagrant electric waves sent out by unauthorized persons in their neighborhood. The practical upshot, however, of the matter is that at present if more than two stations are not established within certain regions, these stations, pair and pair, can communicate with each other freely and regularly by means of ether-wave signals sent out and received by long vertical rods or wires. No state of the atmosphere, and neither darkness nor storm, interrupts, so far as yet found, the freedom of communication."

Messages received by more than one coherer.

During a lecture by Marconi on June 13, 1902, he gave the following as his opinion:

"That he was not at all prepared to say, that under no possible circumstances could a wireless message transmitted between syntonic instruments be tapped or interfered with, but he wished to point out that it is now possible to work a considerable number of wireless telegraph stations simultaneously in the vicinity of each other without the messages suffering from any interference. Of course, if a powerful transmitter, giving off waves of different frequencies,

Marconi on the possibility of intercepting wireless despatches.

ELECTRICALLY HEATED STAMP FOR BOOK COVERS

A stamping press in the bindery of a publishing house. The die descends on the cover inserted by the attendant, and stamps the name of the work thereon in gold leaf. The switchboard for regulating the current used in heating the stamp is seen above

is actuated near one of the receiving stations, it may prevent the reception of messages, but the ordinary systems of communication through wires may be likewise affected."

Transmission of the three Morse dots across the Atlantic

On December 12, 1901, the scientific world was greatly surprised by an announcement that Marconi had succeeded in transmitting a single character, viz., the letter *s*, of the Morse alphabet, which, it will be remembered, consists of three successive dots, across the Atlantic from Poldhu, Cornwall, to St. John, Nova Scotia. Those who had not been fol-

FIG. 183.—Terminal Wireless Telegraphic Station at Glace Bay, Cape Breton.

lowing the progress of wireless telegraphy, believed the announcement to be a hoax, but the probability of the matter was generally accepted by scientific men, and, indeed, the American Institute of Electrical Engineers tendered a banquet to Marconi for his successful experiment. It is an interesting fact that about one year after this date Marconi succeeded in sending across the Atlantic messages in both directions. The antennæ or elevated wires were arranged at Glace Bay, Cape Breton, in the manner represented in Fig. 183. The New York "Electrical World and Engineer," of December 27, 1902, thus refers to this matter:

Trans-atlantic wireless messages sent.

"On Sunday, December 21, the following despatch from Mr. Marconi, dated Glace Bay, N. S., December 21, was received at the office of the Associated Press in this city:

" 'I beg to inform you for circulation that I have established wireless telegraph communication between Cape Breton, Canada, and Cornwall, England, with complete success.

" 'Inauguratory messages, including one from the Governor-General of Canada to King Edward VII, have already been transmitted and forwarded to the Kings of England and Italy. A message to the London "Times' has also been transmitted in the presence of its special correspondent, Dr. Parkin, M.P.'—G. Marconi.

First Marconi transatlantic wireless despatches.

"At the same time, on Monday, in London, the 'Times' announced that it had received by post from Poldhu, Signor Marconi's receiving station in Cornwall, the following message, sent by wireless telegraphy, from the 'Times' ' special correspondent at Glace Bay:

" 'Being present at its transmission in Signor Marconi's Canadian station, I have the honor to send, through the "Times," the inventor's first wireless transatlantic message of greeting to England and Italy.'

"Mr. Marconi also notified Lord Minto, Governor-General of Canada, of the achievement, and received the following acknowledgment by telegraph from Ottawa:

" 'Delighted at your message just received. Warmest congratulations on your splendid success.'—Minto."

Besides the systems of wireless telegraphy of Popoff and Marconi, to whom we have alluded, there are many others; for example, those of Prof. R. A.

Fessenden; the Braun-Siemens and Halske System; the Slaby-Arco and Braun German System; the De Forest System; the Ducretet and Rochefort systems in France; all of whom have successfully transmitted wireless despatches over considerable distances. None of them, however, has yet reached the space covered by Marconi in his system. **Other wireless telegraphic systems.**

It will be interesting to note that the various systems of wireless telegraphy have been now so generally introduced on board ships and at various ports of the world, that it is possible for a passenger on a transatlantic, or other steamer, to learn of important events that have occurred while he is on such vessel. It was only recently that there was published the first newspaper on such a steamer. We allude to the Cunarder, the *Etruria*, that published, on Saturday, February 7, 1903, news which was received from the coast of Ireland, from the Marconi wireless telegraphic station some 70 miles distant. It will be interesting to quote the first paragraph from this paper as an evidence of what can be done in this direction: **Wireless telegraphy in actual use on trans-atlantic steamers.**

"*Steamship 'Etruria,'* February 7, 1903.

"LATEST NEWS PER REUTER'S AGENCY, VIA MARCONI WIRELESS TELEGRAPHY.

"Venezuela question still unsettled. Negotiations discussing various proposals, which appear satisfactory to either party, meanwhile blockade continues. Castro inflicted another severe defeat on revolutionists." **Wireless telegraphic newspaper at sea.**

It is interesting to note that the wireless telegraphic system has been adopted by the United States Signal Service, for use in the Alaskan waters and coast defence, as well as by the United **Wireless telegraphy in every-day use.**

States Navy for use on their men-of-war. It has also been adopted by the navies of foreign governments generally, and by the great insurance firm of the Lloyds, who control some 40 land stations along the coast of Great Britain and Europe.

The receiving apparatus of wireless telegraphic systems are liable to be temporarily thrown out of use by atmospheric electric disturbances. Various devices have been proposed to avoid such disturbances. Quite recently, however, the study of electric meteorology, *i.e.* the study of the electric phenomena of the atmosphere, has been considerably advanced by the use of wireless telegraphic methods. The Popoff System, to which we have referred, was at first arranged so as to register lightning flashes taking place in distant thunderstorms, and was subsequently applied to the transmission and reception of wireless messages. For the purpose of registering lightning flashes, Popoff connected one end of a coherer to an insulated metallic wire placed at the top of a tall mast, while the other terminal of the coherer was put to earth. At every lightning flash, the coherer closed the circuit of a battery, and recorded the flash on the recorder fillet.

Use of wireless telegraphy in electric meteorology.

By placing a coherer on the diaphragm of a telephone, Professor Tommasina, in 1899, contrived the form of simple apparatus, which he called an electroradiophone. He employed this apparatus for making observations of the progress of distant thunderstorms. The apparatus required only a single cell of a dry battery, and the use of a comparatively short line of exterior wires or antennæ, some of which could be placed horizontally. In these cases, however, care was necessary to be taken in order to insulate the ends of the wires. In Fig. 184, right,

Electro-radiophone of Prof. Tommasina

hand side of figure, *a* is the telephone coil, and *b* the telephone diaphragm, while *f* is the filings cavity of the coherer, and *m* the filings; *h* and *i* are the coherer electrodes, and *r* and *s* the telephone terminals. The receiving antennæ consist of some three copper wires, connected through *l* and *k*, with a single dry cell, *i*, placed in the circuit, as represented at the left-hand side of the figure.

FIG. 184.—Tommasina's Electro-radiophone.

Tommasina thus describes some of the curious effects produced by the employment of this interesting form of instrument:

"On September 29, 1900, exactly at midday, the weather was very fine, but the electro-radiophone in the morning continued to indicate by various sounds and distinct shocks that discharges were certainly occurring at great distances. Toward two o'clock the sounds became more and more energetic. Some resembled strong and prolonged thunderclaps at frequent intervals. Some curious results obtained by Tommasina

"Finally, the intervals between the signals became shorter, and at half-past three o'clock the sounds were incessant. The lightning at this time became visible and large clouds commenced to form; no

thunder, however, was yet heard, but in the telephone the noise became progressively more intense. Suddenly it was modified, and a sharp and continuous crackling was heard. Some instants later the rain commenced to fall, and at the same time the first stroke of thunder was heard. I scarcely had time to disconnect the apparatus when a storm of extraordinary force burst forth. The streets were filled with water, lightning occurred without interruption, and several strokes took effect in the vicinity. Later I could hear in my apparatus the last discharges at a great distance."

Storm of extraordinary force.

IV

ELECTRO-MAGNETIC ANNUNCIATORS AND ALARMS

CHAPTER XXIV

ELECTRO-MAGNETIC BELLS

"Switches are required in electric bell work, either for breaking and making a circuit, or for transferring pushes and contacts from one circuit to another."—*Practical Electric Bell Fitting*": ALLSOP

THE rapidity with which an electro-magnet, whose core is made of very soft iron, is able to acquire and lose its magnetism, renders it of great value in signal apparatus. As we have already seen, use has been made of this valuable property both in the case of the electro-magnetic relay and in the Morse sounder and recording apparatus. Electro-magnets enter largely into the construction of bells, annunciators and alarms generally.

Value of electro-magnets in signal apparatus.

The simplest form of electro-magnetic bell is what is called the single-stroke bell. In this bell, as the current passes through the coils of the electro-magnet, the armature is attracted, and the striking lever gives the bell a sharp blow, thus sounding it. As long as the current passes through the coils of the electro-magnet, the armature will remain attracted, but when the current ceases to pass the armature will be released and drawn back to its original position by means of a spring. In other words, the bell will give a single stroke every time the circuit is completed. Bells of this type can be employed for

Single-stroke electro-magnetic bell.

a variety of purposes not only for calls, but also for sending a predetermined code of signals by employing certain combinations of strokes and intervals betwen the strokes for agreed-on signals. A single-stroke bell is shown in Fig. 185. Here the coils E E of the electro-magnet are connected with

FIG. 185.—Single-stroke Electro-magnetic Bell.

the circuit of a push-button and a voltaic battery. The armature A is suspended from a stiff spring in the manner shown in the figure. The striking lever is attached to the lower end of this armature, and is provided with a hammer *m*. In order to prevent the spring from moving the armature too far back on the cessation of the magnetizing current, a stop-screw is placed at *b*, as shown in the figure.

Construction of single-stroke bell.

Sometimes a single-stroke bell is arranged so that two different bells producing different sounds can

be struck alternately. In this case, the electro-magnetic mechanism is placed between the two bells, as indicated in Fig. 186. Such a bell is called a bi-gong or double bell.

Double-gong bell.

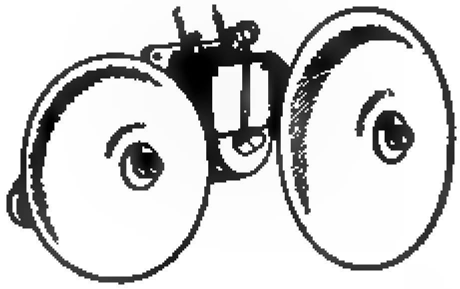


FIG. 186.—Double-gong Bell. This form is sometimes called the Bi-gong Bell.

Most electric bells, however, belong to the trembling or vibrating types, and are so arranged that as long as the circuit remains closed by the distant push-button being maintained against its contact, the bell will continue ringing. The mechanism

Trembling or vibrating electro-magnetic bells.

FIG. 187.—Vibrating or Trembling Bell.

whereby the sounding is continued as long as the current passes through the coils of the electro-magnets, is by the well-known automatic contact-breaker before alluded to. A trembling or vibrating bell is shown in Fig. 187. Here the electro-magnets M M

are connected as shown with the circuit of a voltaic battery and a push-button, by wires or conductors *b* and *c*. It will be observed that *b* is connected to one end of the magnetizing coils through A and B, while the other end is connected through the spring *r*. When the circuit is closed by pressing the push-button, the current passing through the coils M,M, through the wire *b* and post C, and thence through the spring *r* and the post E, is completed. Immediately, however, the electro-magnet attracts its armature, and thus breaks the circuit by separating the armature from the contact with *e*. The magnetism at once disappears from the electro-magnet, and the armature is released, and is moved back by the action of the spring on which it is supported. This again establishes the current, and permits the armature to be again attracted. There will thus be produced a rapidly vibrating movement of the armature, which will be continued as long as the current is maintained.

Operation of the vibrating bell.

Any vibrating or automatic bell can be readily converted into a single-stroke bell in the manner represented in Fig. 188, from Prescott. Here the connections with the circuit of the battery and the push-button are represented at A and S, which are shown in the figure as the positive and the negative terminals of the battery, although it is a matter of indifference which pole of the battery is placed at A and S. When the switch S is connected with the contact E, the bell will sound continuously, since, as soon as the current passes through the coils of the electro-magnet, the armature of soft iron, *e*, will be attracted, and will thus break the contact between the armature and *r*. Instantly, the spring moves the armature *e* again into contact with *r*, thus permitting the electro-mag-

Manner of changing vibrating bell into single-stroke bell.

net again to attract the armature. In this manner, a rapid automatic vibratory motion of the armature will take place as long as the switch remains in con-

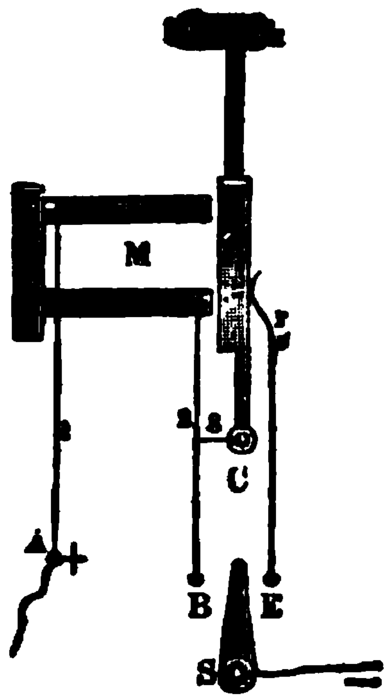


FIG. 188.—How a Vibrating or Trembling Bell may be Changed into a Single-stroke Bell.

tact with E. If, however, the switch S is brought into contact with B, then the bell becomes a single-stroke bell, and will give a single stroke only every time the contact is completed.

The first automatic make-and-break bell was invented by Dr. Werner Siemens, of Berlin, for use in his step-by-step telegraph. The form this took is **The first automatic make-and-break.**

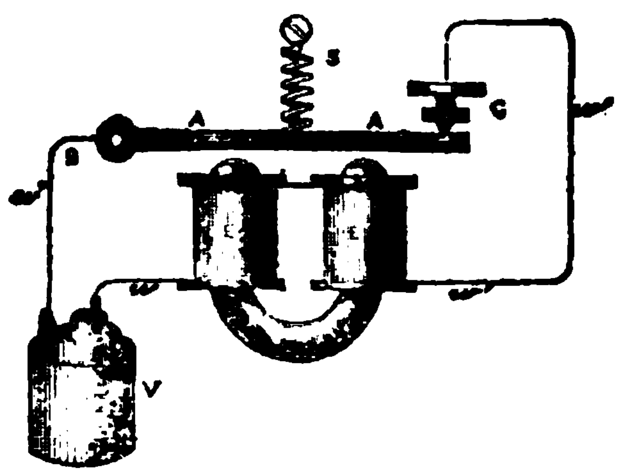


FIG. 189.—Werner Siemens Automatic Make-and-Break.

represented in Fig. 189. An inspection of the figure will show that the operation is exactly the same as

in the vibrating bells already described. The electro-magnet coils E E are placed in the circuit of the voltaic cell V. The armature AA, of the magnet, is supported as shown on the pivot B, and by the spring S. The circuit is completed at the end of the armature by contacts at C. As soon as the current passes through E E, the attraction of the armature breaks the circuit, while the action of the spring S immediately completes it again, thus alternately breaking and making the circuit as long as the cell V continues to send current into the coils E E, on the opening of the circuit. Siemens employed this automatic break and make by causing the to-and-fro movements of the armature to move an escapement, so that the scape-wheel *e*, Fig. 190, carrying a light

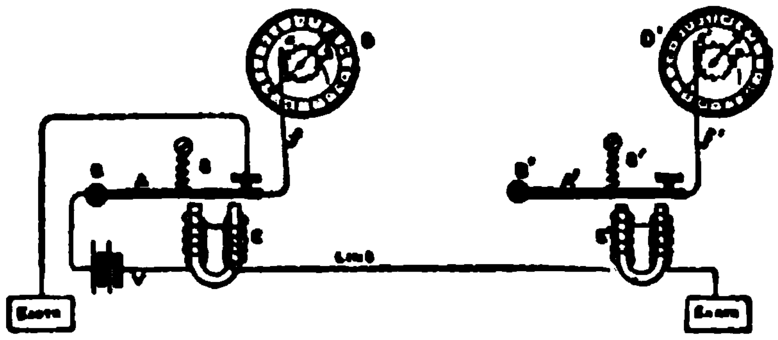


FIG. 190.—Werner Siemens Step-by-Step Telegraph.

pointer *p*, is moved around the circumference of the dial D. As long as the armature of the electro-magnet moves to-and-fro, the pointer will be moved step-by-step over the face of the dial. By sending a suitable number of impulses into the line, Wheatstone was able to telegraph signals by noting where the index stopped at the distant dial D′.

Electro-magnetic buzzer.

A form of vibrating or trembling bell called the buzzer, differs only in the fact that the strokes of the bell are much less pronounced. This is desirable in locations where a loud-ringing bell would be objectionable, as in the case of private offices, where a buzzer is employed to call one to the telephone. In

such cases, in order to increase the faint sound of the buzzing, the bell mechanism is enclosed in a wooden or metallic case, for the purpose of strengthening the sounds by resonance. A form of electric buzzer is shown in Fig. 191.

FIG. 191.—Electro-magnetic Buzzer.

In the electro-mechanical gong or bell, the bell is given a powerful stroke by means of any suitable mechanical mechanism that is thrown into action by **Electro-mechanical gong.**

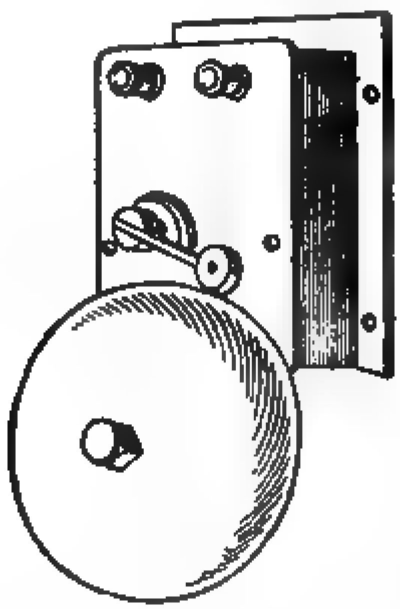


FIG. 192.—Electro-mechanical Gong.

the movements of the armature of an electro-magnet. In the form of electro-mechanical gong represented in Fig. 192, when the hammer is released by

the action of an electro-magnet, it makes a full revolution, passing under the gong and passing up an inclined plane, by means of which it is raised, so

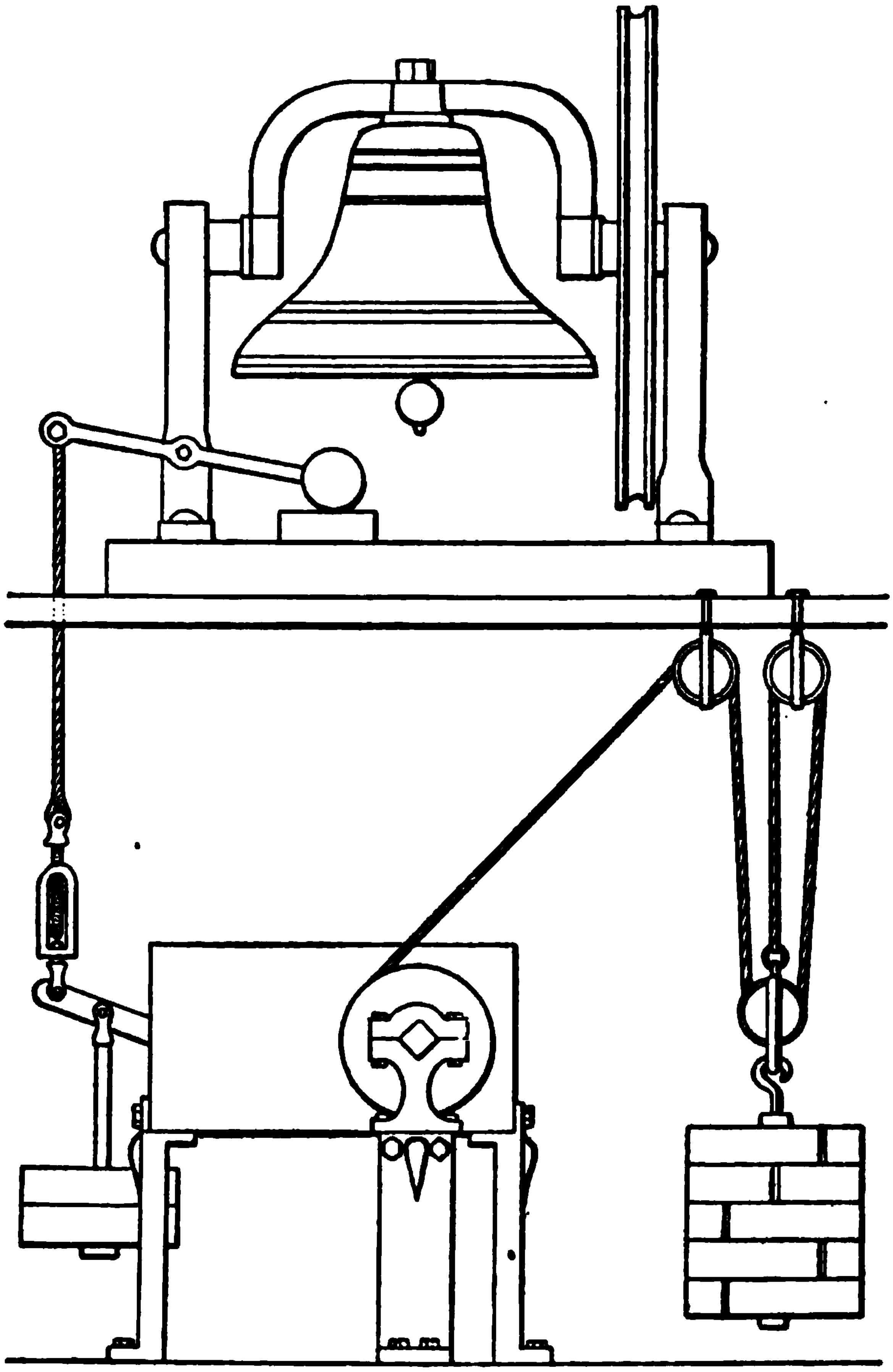


FIG. 193.—Church Bell Striker.

that when it has completed its revolution it strikes the gong with the full speed it has gained during this revolution. The locking and releasing, effected by means of an eccentric, is obtained by means of a

positive motion, which relieves the armature from pressure or strain, so as to permit a comparatively weak current to operate the electro-magnet.

A church or fire bell striker, operated on similar principles, is represented in Fig. 193. The striking mechanism is released by the attraction of the armature of an electro-magnet. The force of the blow is determined by means of weights hung on the striking lever or drum. When the electro-magnet releases the weight attached to the drum, it causes it to make a part of a revolution, and thus move the striking lever. The striking actions are such as permit operation either by the action of an open or closed electric circuit. **Church or fire bell striker.**

It is sometimes desirable that, when the trembling or vibrating bell is set into motion, it may continue ringing at the distant point no matter whether the contact is continued at the push-button, or other point where the contact is established, or not. Such an arrangement would be desirable in the case of a burglar or fire alarm, when the contact had once been momentarily closed. In such a case, the arrangement is called a continuous-ringing bell, in order to distinguish it from a trembling or vibrating bell. A variety of continuous-ringing bells have been devised. One of these is shown in Fig. 194. Here there are three separate binding posts or contacts provided. That marked C is intended for connection with the carbon pole of the battery, while that marked L is for connection with the line wire. Z is provided for connection with a shunt or branch wire connected with the zinc pole of the battery. As soon as the current flows through the coils of the electro-magnet, on the completion of the circuit at the push-button or other contact, the armature is attracted, and thus **Continuous-ringing bell.**

permits a lever contact or dropping arrangement, represented at the lower right-hand side of the figure, to fall, thus putting the battery in connection with the bell, irrespective of the distant push-button or contact. The bell, therefore, will continue ringing until the lever is replaced either by pulling the cord represented at the right-hand side of the figure, or in any other way.

Action of continuous-ringing bell.

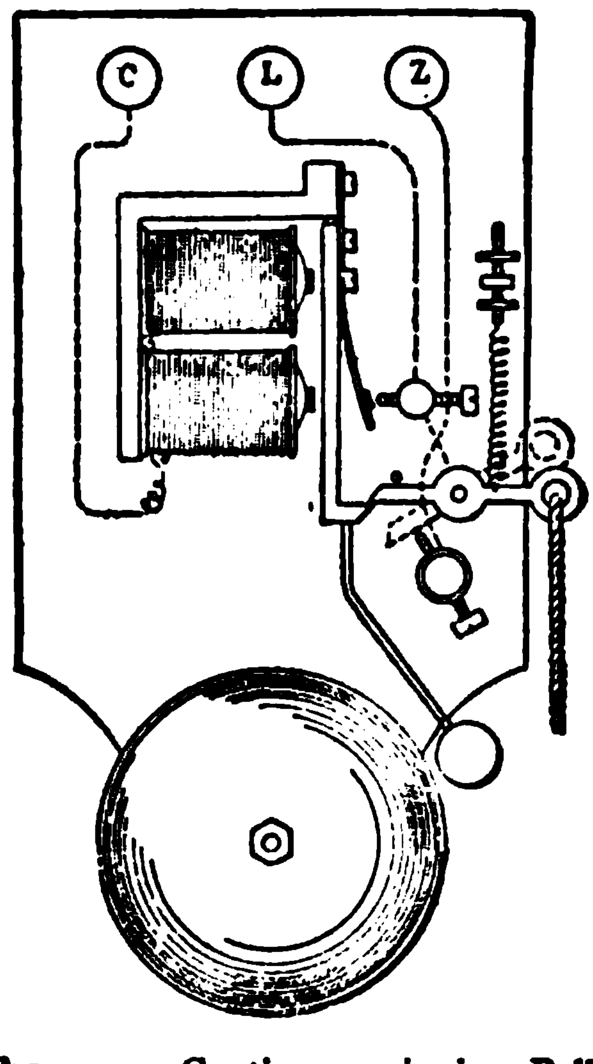


Fig. 194.—Continuous-ringing Bell.

Continuous-ringing relay bell.

The form of continuous-ringing bell above described is not found to be entirely satisfactory in actual use, and is generally replaced by the form of continuous-ringing bell known as the relay bell, represented in Fig. 195. Here Z, L, and C, as before, represent respectively the connection for the zinc, line, and carbon of the battery. On the completion of the current by the closing of the distant push or contact, the circuit is completed by entering at L, passing through the coils of the relay magnet *r*, and

out at Z. On the attraction of the armature of the relay *r*, the lever *g* is released, which then falls and makes contact with *n*. The current now flows from C through the coils of the bell magnet *b*, and the bell continues to ring until the lever *g* is reset by any suitable means. Arrangements have been devised whereby it is possible to reset the lever at a distance by the action of an electric impulse.

FIG. 195.—Continuous-ringing Relay Bell.

Continuous-ringing attachment for bell.

Sometimes, instead of maintaining a continuous ringing of the bell by means of the same battery circuit as that employed to start it ringing, an independent or local circuit is introduced by the action of a momentary impulse sent over the line. A form of bell of this type, provided with a continuous-ringing attachment, is represented in Fig. 196, where 1 and 2, and 3 and 4, are respectively the contacts for the distant battery and for the local battery. On

the passage of the current from the distant battery through the coils of the electro-magnet, *a, a,* the attraction of the armature, *c,* releases the lever, *h,* by the movement of *g,* away from it. *h* now falls, and brings a contact, *l,* into connection with a corresponding contact on a spring, *m,* connected through

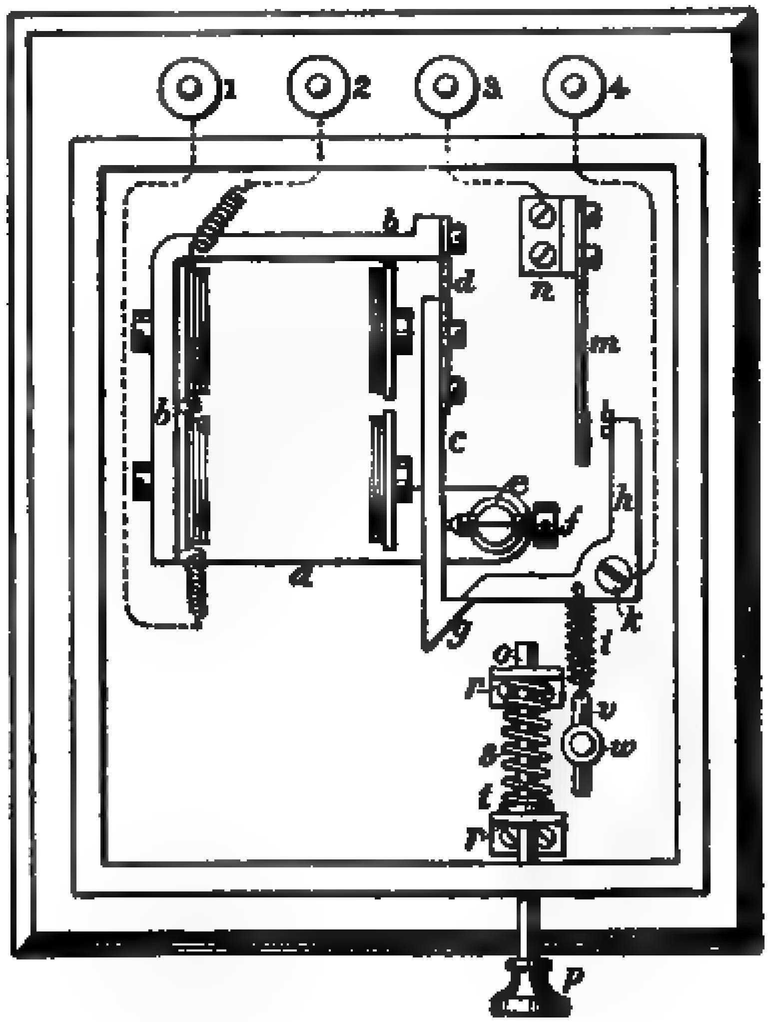


FIG. 196.—Continuous Ringing of Bell by Local Circuit.

n, with the contact, 3, of the local battery, thus bringing into contact the local battery connected with 3 and 4, and causing the bell to continuously sound in the usual manner. A push at *p* is provided at the bottom of the apparatus for the replacing of the lever *h.* The advantage of mounting the contact, *m,* on the spring, instead of against a fixed support, is that the flexible support ensures a wiping

contact between *l* and *m*. Such a contact between the surfaces maintains them bright and free from oxide, which would be apt, otherwise, to collect, if only the ordinary dotting contact were obtained, which would result from placing the contact on *m*, against a fixed support.

A very good form of electric bell, employed as a call-bell for signals in telephony, consists of the polarized bell already described in connection with telephone calls. This bell, as we have seen, is suitable for operation in connection with the current produced by magneto-electric machines, and is in extensive use in connection with hand generators for such purposes.

Polarized bell.

FIG. 197.—Connections of Vibrating Bell, Push, and Cell.

The circuit connections of a vibrating bell, where a single bell only is to be employed, are very simple. Here a single voltaic cell, B, Fig. 197, is connected to the circuit of the push-button, P, and to the bell mechanism, in the manner shown. On the completion of the circuit by pressing the button, P, and causing it to close the contact, as represented at the right-hand side of the figure, the bell will continue ringing as long as this contact is maintained. On

Connections for single bell, cell, and push-button.

the removal of the finger, a spring breaks the contact and the bell stops ringing.

Of course, it is not necessary to employ a metallic circuit, since the ground or earth can be employed for the return circuit, as in telegraphy. An excellent ground can be obtained by making use of a water main or pipe. In doing this, however, care must be taken to ensure a good contact between the

A good ground necessary.

wire and the water pipe. This is best done by scraping a part of the water pipe clean with a knife, and then twisting several turns of bare copper wire around the pipe, and soldering it. It will be necessary, however, first to clean the wire by a piece of emery paper. Unless a good ground connection is obtained, much difficulty will be experienced in operation, from the high resistance at an imperfect contact. The mere wrapping of a piece of greasy bare wire around the surface of a dirty pipe will give an exceedingly poor contact, and one which will probably cause considerable trouble.

It is evident that various means can be employed for closing the contact of an electric circuit, and so throwing the electric bell into action. All that is necessary for this purpose is some means whereby two parts of a circuit, that are separated a short distance from each other, can be brought into contact

Pushes and pulls.

mechanically or otherwise, and in addition to this, means for separating such contact either by hand or automatically, by the action of a spring or weight. In the case of apparatus similar to the push-button, the breaking of the circuit is generally obtained by the action of a spring. In some cases, however, instead of closing the circuit by pushing a button, it is more desirable to close it by means of a pull, in this case, the contact-making device taking the shape

of an ordinary door-pull. A contact of this latter type is called a "pull," in order to distinguish it from the ordinary button or "push." Sometimes, however, the contact, instead of being fixed to a wall or other support, is suspended by a contact cord, so as to resemble the tassel of a bell cord. It is then called a

Pressels.

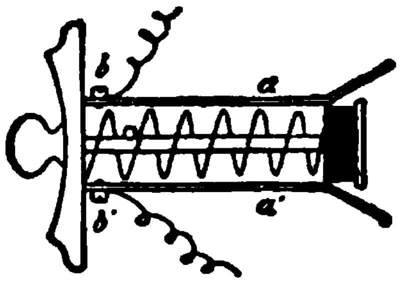


FIG. 198.—Electric Pull for Making Contact.

"pressel." A form of pull is represented in Fig. 198. The battery terminals are connected with two metallic springs, *a, a'*, by binding screws at *b* and *b'*. When the knob is pulled, a metal collar is drawn in between the springs, *a, a'*, and closes the contact by bridging the interval between *a* and *a'*. On releasing the pull, a spring pushes back the collar, and thus breaks the contact.

Where it is desired to be able to ring the same bell from two or more different push-buttons or other contacts, the separate pushes or contacts must

Contacts in parallel.

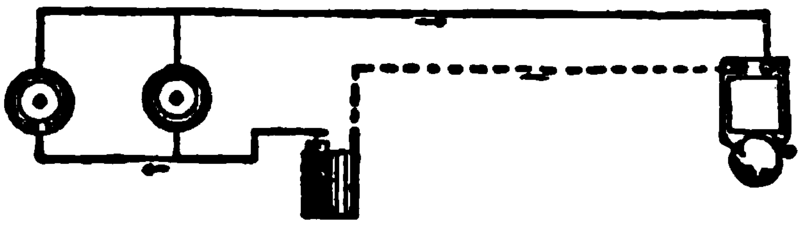


FIG. 199.—Push Buttons in Parallel.

be connected with the line in parallel, in the manner shown in Fig. 199. Such a connection will cause the bell to ring whether one or both pushes are in contact with the line wires at the same time.

Where it is desired to ring two or more bells from the same push-button, the bells may be placed across

How to ring several bells by a single push-button

the circuit in parallel, in the same manner in which incandescent electric lamps are placed across the lighting mains. Here, since the current divides itself into two or more parts, according to the number of bells employed, it is generally necessary to employ either larger cells, or to connect a number of separate voltaic cells in parallel.

Bells in series.

Another method for ringing a number of bells from a single battery is to connect the bells to the line wire in series. This will be a practicable method where the bells are single-stroke bells. If, however, they are of the vibrating or continuous-ringing types, they will not be found to work satisfactorily, unless the bells employed are especially arranged for such purposes; viz., bells which operate not by breaking the circuit, but by shunting it around the magnetizing coils. With such an arrangement, no matter how many bells there may be in series on the same line, the circuit will never be broken. This method, however, is objectionable, since the bells will not sound as loudly as bells of the ordinary type.

Use of relays for ringing distant bells.

Where it is desired to ring a bell at a considerable distance without employing a very strong battery, a relay is employed, which throws a local battery into the circuit, and so rings the bell. This method is similar to the action of the relay in electro-magnetic telegraphy. Where relays are employed, a number of bells can be operated by causing the relays to close the circuit of local batteries. For example, if the push-button, P, Fig. 200, be closed, a current will flow through the coils of the relays, R^1, R^2, successively, thence returning to the battery through the earth plates, E, E. These relays, closing the local circuits represented in the figure, will cause the bells, B^1, and B^2, to ring. If such bells are

vibrating bells, they will continue ringing as long as the contact at P remains closed. If they are single-stroke bells, they will only give a single stroke for each closing of the battery circuit.

Various forms of voltaic batteries are employed for ringing bells. It will be found, however, that the best results are obtained in practice, by the employment of the Leclanché cell, which we have al-

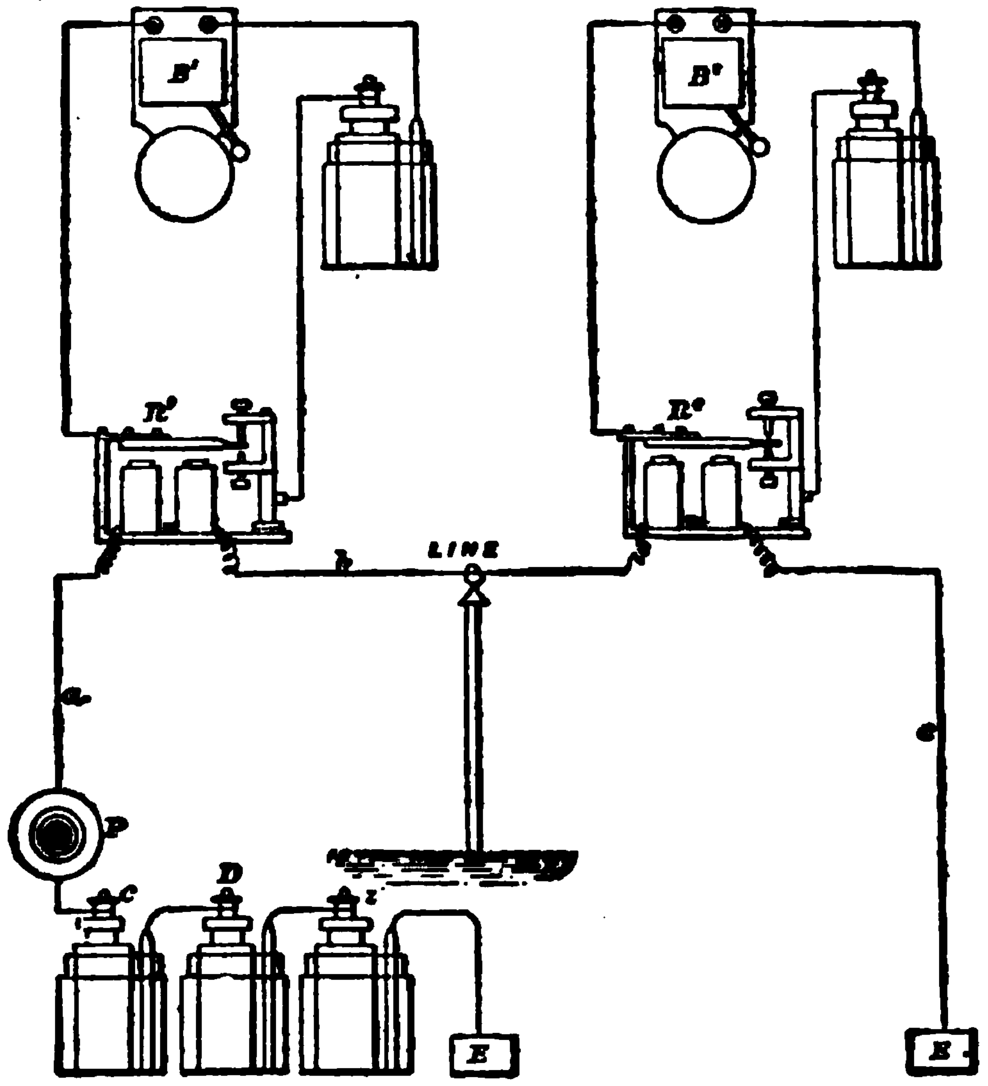


FIG. 200.—Method of Ringing a Number of Bells by Relays in Series.

ready described. For all open-circuited work, these batteries give the best results, since they are readily kept in good working action. Although, as already remarked, the cells polarize rapidly, yet, since the current they are required to furnish is only needed for a short time, and long periods of rest are apt to occur between the times that the bells are rung, the Leclanché cell can readily depolarize from the action of the black oxide of manganese mixed with the

Suitability of Leclanche's cell for open-circuited work

carbon. When properly set up, such batteries will continue to furnish current for periods varying from half a year to 2½ years, with a single charge of chemicals, although, at intervals between these periods, it will be necessary to inspect the cells at more or less regular intervals, in order to see that no mishap has occurred. Sometimes, it will be found, for example, that a white salt is creeping over the sides of the glass jar. Under such circumstances, the jar should be removed, washed, and dried. If the zinc assumes a deep black color, and a strong smell of ammonia is observable, the indications are that a short circuit has occurred, and that the battery is rapidly exhausting itself. This short circuit must be discovered and remedied, and under such circumstances, it is advisable to recharge the cell. Care, too, must be observed to maintain the level of the liquid in the glass jar at a normal height. This is done by occasionally filling the jar with pure water, so as to replace the water lost by evaporation. If the liquid in the glass jar becomes milky or white, it can be remedied by adding crystals of sal-ammoniac, the white salt employed in charging the jar.

Care and inspection of battery.

Sometimes some form of bichromate, a Fuller cell, or a form of Edison-Lalande cell, may be employed in the case of large buildings like hotels, where a considerable battery current is desired. In all calls operating on closed-circuited systems, some form of Daniell's constant battery must be employed, which is entirely free from polarization. Referring to the suitability of the Leclanché voltaic cell for bell work, F. C. Allsop gives the following as his opinion:

Allsop on Leclanche batteries.

"A severe and prolonged test, extending over many years, has proved that for general electric bell work the Leclanché has no equal; though, in

MAKING HATS BY ELECTRICITY

Power and heat necessary for the forming of hats are both obtained from electrical installations in many hat factories, with excellent results. In the photograph the hats revolving on spindles are being shaped by electric heaters

large hotels, etc., where the work is likely to be very heavy, it may, perhaps, be preferable to employ a form of the Fuller bichromate battery. It is very important that the battery employed should be a thoroughly reliable one and set up in a proper manner, as a failure in the battery causes a breakdown in the communication throughout the whole building, while the failure of a push or wire only affects that portion of the building in which the push or wire is fixed. A common fault is that of putting in (with a view to economy) only just enough cells (when first set up) to do the necessary work. This is false economy, as when the cells are but slightly exhausted the battery power becomes insufficient; whereas, if another cell or two had been added, the battery would have run a much longer time without renewal, owing to the fact that each cell could have been reduced to a lower state of exhaustion, yet still the battery would have furnished the necessary power; and the writer has always found that the extra expense of the surplus cells is fully repaid by the increased length of time the battery runs without renewal."

Dangers of false economy.

CHAPTER XXV

ELECTRO-MAGNETIC ANNUNCIATORS

"Go call a coach."—*Chrononhotonthologos,* Act I, Scene I

Electro-magnetic annunciators.

AN electro-magnetic annunciator is a device for automatically indicating the points at which one or more electric contacts have been closed. Annunciators are employed for a great variety of purposes. For example, in hotels they are employed for indicating the number of a room the occupant of which desires some service. In its simplest form, an annunciator is operated from the room by the guest pressing a push-button, and thus closing an electric circuit. The closing of this circuit is indicated at the office by the fall of a drop or shutter, or by the movement of an electro-magnetic needle. In the former case, the falling of the drop or shutter discloses the number of the room calling. In the latter case, the needles are placed over numbers corresponding to the numbers of the room. The needle is moved out of its normal position, generally a horizontal one, into a vertical or inclined position. The electro-magnetic annunciator is similar in its construction and operation to the annunciators employed on the switchboards of central telephone stations.

Hotel annunciator.

A form of electro-magnetic annunciator suitable for use in hotels is shown in Fig. 201. Here the push-buttons connected with rooms No. 28 and No. 91 have been operated by guests who have called

for some service. This is indicated in the figure by the drops from these two electro-magnets having fallen, displaying the numbers. At the same time, the current that automatically drops the shutter rings an electro-magnetic bell, calling the attendant to the annunciator. As soon as the attendant has noted the numbers of the rooms calling, he replaces the drops by the movement of a lever, or some other mechanical device provided for such purpose.

Fig. 201.—Hotel Annunciator.

Sometimes the call is indicated by the movement of a needle, instead of by the fall of a drop or shutter. A hotel annunciator of the needle type is represented in Fig. 202. The call-bell is indicated at the top of the annunciator. The device for resetting the needles is placed at the bottom of the figure. In this form of annunciator a call is indicated by the particular needle, placed immediately below the number corresponding to the room, being made to assume

Needle type of hotel annunciator.

a position midway between a horizontal and a vertical position. In some forms of needle annunciators, a call is indicated by the needle changing from a horizontal to a vertical position. In the hotel annunciator shown in this figure, the device for resetting the needles takes the shape of the handle represented in the lower part of the annunciator.

Fig. 202.—Hotel Annunciator. Note the resetting device near the bottom of the apparatus.

Elevator annunciator.

Electro-magnetic annunciators are now almost universally employed in elevators. The needle annunciator is very commonly employed for this purpose. Such instruments must necessarily be positive in their action, and of a type that would not be liable to be deranged by the jars to which they are subject in the elevator cars. A form of elevator annunciator is shown in Fig. 203.

Various types may be employed for releasing the drop or shutter. In that shown in Fig. 204, called

the lock gravity drop, the attraction of the armature of the electro-magnet releases the drop or shutter,

FIG. 203.—Elevator Annunciator. Note that the third and fourth floors have called for elevator service.

which then falls by the action of gravity, automatically displaying the number printed back of the

FIG. 204.—Lock Gravity Drop for Annunciator. Note that the drop has fallen, revealing the number calling, *i.e.* 6.

drop. Such devices are either replaced by hand, or are made self-restoring, as in the case of the telephone annunciators.

Lock gravity drop.

In some forms of self-restoring drops, the drop is reset by the action of a current sent through an additional electro-magnet. Another form of self-restoring annunciator is called the pendulum indicator. Here the electro-magnet has its armature so arranged that when suddenly drawn back, on the passage of the current through its coils, it releases a pendulum that will continue to swing to-and-fro for several minutes before coming to rest. When it does come to rest it assumes the position in which it is ready again to be set swinging when another impulse comes through the coils of the electro-magnet. In this way the indicator is self-restoring. In order readily to call attention to the to-and-fro movements of the pendulum indicator, it is sometimes provided with a reflecting mirror-like surface, so that its movements can be readily seen in a dimly lighted room.

Pendulum annunciator indicator.

Sometimes, where it is desired that an answer shall come back from the distant point indicating that the ringing of the bell at such point has been heard, various arrangements of circuits have been devised. That shown in Fig. 205 is suitable for operation where each of the rooms signalling is provided with an electric bell, which can be readily rung by the attendant who answers the distant bell. Here a single battery, B, has its terminals connected with the circuits marked 1, 2, and 3, respectively. Push-buttons, P, P, P, and electric bells, *b, b, b,* are placed in each of the three rooms in parallel with the circuit wires in the manner shown. Under these circumstances, a person in any of the rooms can, by pressing the push-button, P, P, or P, ring the distant bell, R. At the same time, in order that the person calling may know that such call has been heard, he will listen for the bell in his room to sound. This can

Answer-back system.

be done by the party receiving the call pressing the push-button at P′, and ringing all the bells, *b, b, b.* This system is open to the objection that the bells are necessarily rung in all of the rooms. It may be modified by employing a greater number of circuits, so that the return or answer-back call shall be heard only in the room in which it is desired.

FIG. 205.—Answering-back System.

A great improvement on the simple push-button system just described is now generally employed in large hotels or other similar buildings, in the shape of a device called a teleseme. Here a dial, Fig. 206, is placed in each room, on the face of which are marked in printed characters all the articles or services the guests are apt to need. The circuit connections and apparatus are so arranged that on placing an indicating finger on the name of the particular article or service desired in sending a signal to the office, the need can be indicated without waiting for the coming of the call-boy.

Improved form of annunciator signals.

In the form of annunciator employed in connection with the teleseme, called the electrolytic annunciator, a number of separate electrolytic cells, Fig. 207, are arranged on the surface of a board, provided with a transparent cover. The closing of any distant push-button, or contact, is indicated on the annunciator board by a chemical decomposition pro-

Electrolytic annunciator.

FIG. 206.—The Teleseme or Hotel Call. To send a call thus, the indicating finger or index is moved so that its narrow end rests on the name of the particular thing needed, and the push button *P* is then pressed by the hand.

duced in the liquid of the electrolytic cells; *i.e.*, a reddish brown film that is produced on the surface of the liquid. The surface is cleared by a current of air sent through the instrument.

Annunciator service in large hotels is now, however, rapidly being replaced by telephones, that

communicate with a central switchboard at the hotel office. By this means, a guest can far more readily make known his wants than by any method of annunciators yet devised.

Telephones vs. annunciators.

From a historical standpoint, the annunciator was evolved before the electro-magnetic bell. The earliest form of annunciator may be conceived to be

FIG. 207.—The Electrolytic Annunciator. Note the fact that numbers 34 and 55 have called.

the well-known device called the Schweigger multiplier, produced in 1819, to which we have already referred, and which, it will be remembered, consists essentially of a number of turns of insulated wire, with a magnetic needle suspended at the centre of the coil. On the passage of the current, the needle moves either to the right or to the left, according to the direction of the current, or the direction in which

Schweigger's multiplier the first annunciator.

the coils are wound. Here the needle takes the part of the annunciator.

But apart from the multiplying coils, the annunciator took a more positive shape in the needle telegraphic instrument of Wheatstone and Cooke, which was evolved between the years 1837 and 1840. Here, in addition to the motion of the needle over the dial, a call-bell was employed, the electro-magnets of the bell being operated by means of a local battery thrown into action by closing the points of a relay.

CHAPTER XXVI

BURGLAR, FIRE, AND OTHER ALARMS

"Set a thief to catch a thief"
—*Old Proverb*

ELECTRO-MAGNETIC annunciators are employed for various purposes besides those already mentioned. The ease with which the closing of a contact at any distant point can sound an alarm and indicate the exact place at which such contact has been closed, enables various systems of burglar, fire, temperature, and water-level alarms to be readily arranged.

Use of annunciators for alarms.

In the case of burglar alarms, the electric contacts are placed on doors, windows, stairways, or under mats or carpets in a room, so that the mere opening of the door or window, or stepping on the stairway, or walking over the floor of a room, will sound an alarm, either in one of the rooms of the house, or, when the house is closed, in the street; or, still better, in the nearest police station. In order to prevent burglar alarms from being sounded during the daytime by the regular occupants of the house, switches are arranged so as to disconnect the battery. Since, in the case of forgetfulness properly to open or close such switches, the burglar alarms may fail to operate, the plan is frequently adopted of causing the opening and the closing of the circuits to be automatically effected by means of a good clock.

Burglar alarms.

In any system of burglar alarms, since a long time, often weeks or months, may elapse without

such alarms being sounded, great care is necessary in order to select contacts of such a character that they will be ready at any time to perform their work. For the reasons already pointed out, wiping contacts are to be preferred to dotting contacts, since the former keep the contact surfaces clean from oxide.

Contacts for burglar alarms.

Burglar-alarm contacts have been devised in great variety, so arranged as to cause the alarm to be sounded either when the circuit is made or broken.

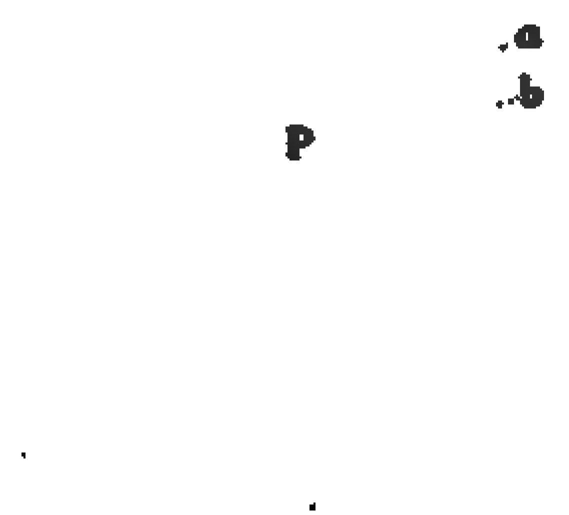


FIG. 208.—Window-spring Contact for Burglar Alarm.

Window burglar-alarm contact.

In the form of window burglar-alarm contact, represented in Fig. 208, a contact is made on the opening of the window. Here an arm or projection is so arranged that, when the plate A A is fastened into the window-jamb above the window, so that when raised the projection P is moved, and a contact established between the points *a* and *b*, the window can not be raised without an alarm being sounded.

Burglar-alarm contacts of a similar description may also be placed on the jamb of a door, so that the opening of the door will close the contacts. A

form of such contact is represented in Fig. 209. When this device is employed on a window, it is placed on a sill, so that, on shutting, the window presses against the projection *r*, and breaks the contact between *a* and *g*. When, however, the window is raised, the spring moves the contact *a* against *g*, thus closing the circuit. When such a contact is placed on a door-jamb, on closing, the contact *r* is moved, thus breaking the contact between *a* and *g*, while the opening of the door permits the spring to close the contact.

Burglar-alarm contacts for windows or doors.

FIG. 209.—Door or Window Contact.

It is evident that, in any system of burglar alarms in which the alarm is sent only when the contact is closed, if the circuit be cut, at either of the contacts at the doors or windows, the doors or windows can be opened without sounding an alarm. In order to avoid this, a system of open-circuited burglar alarms may be employed. In such cases, the opening of the circuit, by the cutting of the wire, would instantly sound an alarm. This may be done either by using a special form of bell, or by using a relay, which automatically inserts the bell into the circuit of a local battery.

Closed-circuited systems of burglar alarms.

A special form of bell, operated by some battery other than that which sounds the alarm, is repre-

sented in Fig. 210. The bell is of the vibrating type, but is provided with three contacts, at 1, 2, and 3, the circuit connections with the battery D being as represented. Here a Daniell's constant cell must be employed, since the circuit is continually closed. A burglar-alarm contact is placed on a safe at C, and is so arranged that, opening the door breaks the circuit, and causes the ringing of the bell in the following manner. As long as the contact C is closed, a current flows from the battery D, from *c*, through *a*, switch S (provided so as to prevent the bell from ringing during daytime, when so de-

Closed-circuited system of bells.

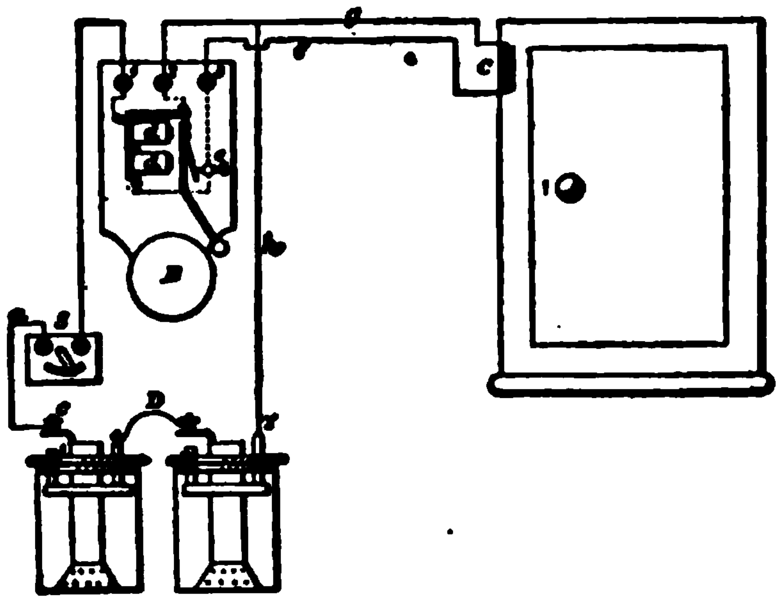


FIG. 210.—Closed-circuit System for Bells.

sired), and terminal 1, of the bell, through the magnet coils, *d, d,* contact post *e*, terminal 3, and wires *g* and *h*, back to the battery. As long as the magnetic cores *d, d* are magnetized, they attract the armature, so that the contact at *e* is broken. When, however, the door of the safe is opened, or when the circuit is broken or cut in any place, the armature *dd* is released, and a contact being made at *e*, the bell will ring, and will continue to ring until the switch S is moved, since the circuit will now be completed through the bell as follows: From the pole *c*, of the battery, through *a*, S, terminal 1, and bell coils *d, d,* contact post *e*, armature terminal 2, and wire *h*, back to the battery.

Action of bell on closed circuit.

The method of ringing the bell on the breaking or opening of the circuit by the movement of the relay is represented in Fig. 211. Here there are two batteries, one, D, the main battery, of the gravity Daniell type, and the other, E, a local battery of the Leclanché type. The main battery is placed in the circuit of the relay R, and the burglar contact at C, on a safe or other door that is to be guarded. As long as the contact at C remains closed, or the circuit remains uncut, the relay attracts its armature, and thus breaks contact with the screw *e*. As soon, however, as the circuit is broken, the contact at *e* is

Closed-circuited system with relay.

Fig. 211.—Closed-circuited System with Relay.

closed, and this closes the local circuit of the battery E, through P, S, G, B, L, *f*, *e*, and the armature of the relay, back to the battery at N. Of course, in the closed-circuited system of burglar alarms, the separate contacts must be placed in the circuit in series, and not in parallel, as in the open-circuited systems.

A form of burglar alarm, suitable for a house, is shown in Fig. 212. Here a clock automatically disconnects the circuits that are connected with the lower bar, and also rings the servants' bell at any time it may be desired, by suitably setting the central dial on the clock. The different rooms, or

Burglar alarm for house.

points of contact, are as represented on the annunciator drops. The galvanometer placed below the clock is intended to show the strength of the battery, so as to indicate whether it is ready for action. Switches are provided for the purpose of making a number of tests, showing the condition of the system. One of these switches is provided for the stopping of the bell after it has been started by the

FIG. 212.—Burglar Alarm for House.

opening or closing of the contacts. On many burglar alarms, an incandescent lamp is placed either in the alarm itself, or in a position in front of the alarm, which is automatically lighted on the sounding of an alarm.

Advantages of closed-circuited system.

Of the two systems above described for ringing bells on the opening of the circuit, the relay is the safer, since, in the first system, the closing of the contact, as by shutting the door of the safe, will stop

the ringing of the alarm. The closed-circuited system, besides affording protection against the burglar cutting the circuit of the wires, also affords a ready means for testing the condition of the entire system; for, should any contact fail to close, the ringing of the bells would indicate that a break existed somewhere, and that, therefore, a necessity existed for carefully examining the line.

A system of electric annunciators is especially adapted for giving early intelligence of a fire. This is evidently of the greatest importance, since the sooner the firemen can get at work, the greater their chance of being able to rapidly extinguish the fire. Systems of fire alarms are now established in practically all important cities in the United States. **Fire alarms.**

The essentials of a system of fire-alarm annunciators, or, as it is frequently called, fire-alarm telegraphy, consists in a central office or station, connected with a number of separate stations by means of electric conductors that extend throughout the district to be protected. Fire-alarm circuits are always metallic circuits. At various points on such conducting lines signal boxes are established. These are generally placed in the street, though sometimes they are inside buildings. These boxes are for the purpose of sending signals to the central office, and thus give notice of the exact location of a fire. As soon as the central station receives this information, it sends signals to the engine houses nearest to the fire. In case of a severe conflagration, where a general alarm is sounded, calls are sent to all the fire stations. These calls may be sent out from the central station either by means of operators, or, in some systems, they are sent out automatically. **Fire-alarm telegraphy.**

A fire-alarm system.

Fire-signal boxes operate on the same principle as the district-telegraph call boxes. The pulling of a handle releases a detent, and permits a wheel to be rapidly moved by means of clock-work. During this rotation, the wheel automatically makes and breaks the circuit a number of times, and thus transmits into the line a number of electrical impulses, that correspond with some arbitrary signal, indicating the number of the box. These impulses pass over the line wire, and are received at the central office, where they cause an alarm bell to give a stroke for each impulse, the number of times and the intervals between the strokes corresponding to the signals sent. In many systems of fire-alarm telegraphy, besides sounding the bell, a record is made on a registering or recording instrument, as in the Morse system of telegraphy.

Fig. 213.—A Form of Fire-alarm Box. To sound an alarm break the glass in the cover of the alarm-box.

Fire-call boxes.

Fire-call boxes are arranged so as to prevent their being maliciously operated for the purpose of sending false alarms. They are either opened by means of keys, placed in the hands of special officers only, or, when they can be operated by other persons, they are generally so arranged that the sending of the alarm at the same time causes a gong to sound, thus calling the attention of the people in

the street to the alarm having been sent. Some fire-alarm boxes are arranged so that the alarm can only be sent by the breaking in of the glass front of the box. Such a box is represented in Fig. 213, where the method for sending the signal is clearly indicated by the lettering on the box. This breaking of the glass front automatically closes the circuit, and thus sounds an alarm at the central office. The method whereby this is accomplished is very simple. A spring is endeavoring to close the contact by the

A fire-alarm box that sends an alarm when the glass cover is broken.

FIG. 214.—Fire-alarm Signal-box. Note the instructions on the door of the signal-box.

movement of a plug. This plug presses against the surface of the glass, and is thus prevented from completing the contact. As soon as the glass is broken, the spring moves the plug and closes the contact.

A form of fire-alarm box, employed in the fire-alarm system of Chicago, is shown in Fig. 214. The outer door, which is of the keyless type, is readily opened by turning the handle to the right. The inner doors operate a short-circuit switch when

A Chicago type of fire-alarm box.

closed, thus cutting out from the circuit all parts except the signal wheel. The signals are transmitted from the box by a wheel provided with notches in its circumference, that make and break the circuit in a manner which represents the number and location of the box.

District telegraph messenger call box.

In the system of district telegraph messenger call boxes, calls can be sent to a central office where there are messenger boys, special officers or policemen, and firemen. On the pulling of the handle of the

FIG. 215.—American District Telegraph Messenger Call Box.

call box, there is automatically transmitted to the central station a number of electric impulses, which both give the number of the box and indicate the character of the service that is required. In the multiple district call box shown in Fig. 215, means have been provided for four different calls—*i.e.*, for a watchman, for a messenger boy, for a policeman, for the firemen—and for some special service, such, for example, as a doctor or a carriage, as may be agreed upon.

In order to send a call, the handle is pulled down until it touches the stop marked watchman in the

figure. On the handle then being released, the wheel inside the box is rotated, and transmits into the circuit a number of makes and breaks, that follow one another at intervals, according to the location and number of teeth on the circumference of the wheel, there being thus sent to the central office impulses that indicate the number of the box and the character of service required, in this case a messenger boy or watchman.

If the little stop near the word watchman is raised so that the handle may be turned around sufficiently far to reach the word police, fire, or special, and is liberated from any of these points, additional signals will be sent into the line, which will send an additional number of impulses into the receiving apparatus, indicating, as before, the number of the box, and the special character of service required.

How the extra calls are sent.

Where it is desired to maintain the same temperature in any locality, such, for example, as a hothouse, incubator, or room, a variety of devices may be employed for sounding an alarm as soon as a certain temperature is reached. One method of operating such alarms is by means of an ordinary mercurial thermometer. In the form represented in Fig. 216, an ordinary thermometer is provided, only, instead of the thermometer tube being hermetically sealed at the top, it is provided with an air-tight rubber cork, through which passes a metallic rod *r*. This rod can be lowered or raised in the thermometer tube, so that its lower end can be placed at any desired level. It will be evident that, as soon as the temperature has reached such a height that, by the expansion of the mercury, the lower end of the metallic rod is reached, the contact between *r* and *r′*, placed in the circuit of a voltaic

Temperature alarm.

Method of operation of the mercurial temperature alarm.

cell and an alarm bell, will be closed, so that the alarm will sound as soon as this temperature is reached.

In a thermo-static alarm, a compound bar of brass and steel, B, S, Fig. 217, is formed by riveting together two straight bars of brass and steel respec-

FIG. 216.—Mercurial Temperature Alarm.

tively, and suspending them in the manner shown. Contact pieces are placed at C and H, as well as on the sides of B and S, opposite these contact points.

Construction and operation of thermo-static alarm

A split battery is connected at its middle point with the central terminal T, and with its positive and negative poles at the remaining terminals T, T. Any decrease in temperature will cause the compound bar to move toward C, thus closing the contact through one-half the battery. On the other

hand, any increase in temperature will cause the bar to move toward H, thus closing the contact with the other half of the battery. In this manner, a simple fire-and-frost alarm can be obtained for sounding an alarm when the temperature either falls below or rises above a certain predetermined limit. When it is desired automatically to maintain the temperature, circuit arrangements can readily be provided whereby, on the fall of temperature, an electro-magnet will open a register, and thus in-

Electric device for automatic control of temperature.

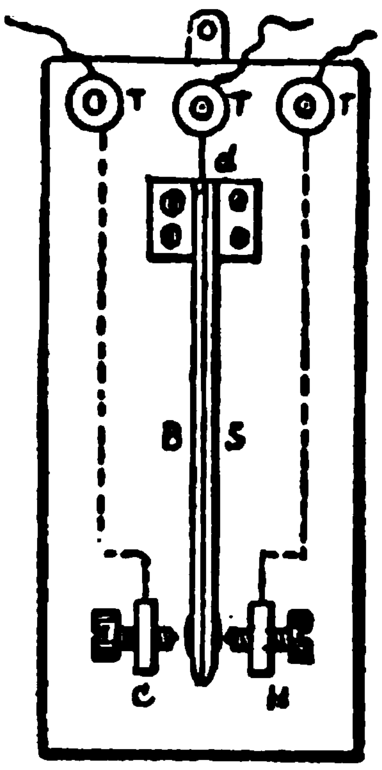


FIG. 217.—Thermo-static or Temperature Alarm. Note how an in-increase of temperature, by bending the rod in one direction, closes one of the contacts, while a decrease of temperature, by bending the rod in the other direction, closes the other contact.

crease the temperature of the room. On the other hand, on the increase in temperature closing the other contact circuit, arrangements may be such that an electro-magnet will close a register; or, in the case of a smaller space, such as would exist in the case of an incubator, an arrangement could be devised whereby an incandescent lamp could be turned on when the temperature fell too low, and turned off when it became too high.

Where it is desirable to send an alarm whenever

a liquid level varies in height, some form of liquid level alarm is employed. In the form represented on the left-hand side of Fig. 218, a ball float is provided with an arrangement for closing the circuit, and ringing a bell as soon as the level of the water rises above a certain predetermined point. In some cases, the closing of the circuit at such a point causes an electro-magnet to shut off the water supply. At the right-hand side of the figure a liquid level alarm is shown that is provided with two ball

Liquid level alarm.

Fig. 218.—Liquid Level Alarm.

floats. Here an alarm will be sent if the water is either too high or too low. As before, an electric device may be employed which turns off the water when the level attempts to pass above the desired height, and turns it on when it passes below it.

Electric door opener.

An electro-magnet is sometimes employed for the purpose of opening a distant door or gate, and thus saving the time required in going to and from the same to open it by hand. Various devices may be employed for such purposes. In that represented in Fig. 219, the attraction of the armature of an elec-

tro-magnet draws in the latch, and thus permits the door to be opened.

It is evident that doors or windows may be locked as well as unlocked by electro-magnetic means. In

FIG. 219.—Electro-magnetic Door Latch for Automatic Door Opener.

order to be able to leave the window of a bedroom safely raised while asleep at night, a device may be attached to the sash, represented in Fig. 220, so placed that the sash is locked in any desired position.

Electro-magnetic window lock.

FIG. 220.—Electro-magnetic Window Lock. On the passage of the current through the magnet coil the sash is unlocked on the cessation of the current. The action of a spring locks the sash.

The circuit of the electro-magnet is so connected with an alarm bell and a voltaic cell, that any attempt to move the sash will result in closing the circuit and sounding an alarm.

Yale-lock burglar-alarm switch.

Where a door has been provided with a burglar-alarm contact, and the alarm has been set for the night, in order to permit an authorized person to enter the house without disturbing the occupants, a device called a Yale-lock burglar-alarm switch may be employed, as represented in Fig. 221. The apparatus consists of a switch so devised that, when placed in a certain position by the insertion of a regular Yale key, it will permit the door to be opened without sounding the alarm.

FIG. 221.—Yale-lock Burglar-alarm Switch.

Electric programme clock for automatically sounding certain predetermined hours and so forth.

By means of electric contacts placed on the hands or other parts of a clock, circuits can be opened and closed for a variety of purposes; for example, to sound an alarm at a certain hour. Such arrangements are generally employed in cases where systems of electro-magnetic bells are installed in private houses. A number of such contacts may be provided for different hours of an entire day, so that an alarm bell will be automatically sounded as such hours are successively reached. Such a clock is called a programme clock. For the purpose of being able readily to change the times at which the bell shall be sounded, there is provided a series of contacts on a part of the clock called the programme dial. A clock of this character is of value in schools, factories, etc., where it is desired to indicate the close of certain periods of time without necessitating constant care on the part of an attendant. A clock of

this description is represented in Fig. 222. The programme dial is shown as placed below the ordinary clock dial.

FIG. 222.—Electric Programme Clock.

Where a night-watchman is required to visit certain parts of the building he is employed to watch, at certain times during the night, it is important to know whether or not he is faithfully discharging

Watchman's time detector.

FIG. 223.—Watchman's Electric Time Detector. Note the record sheet of paper below the clock dial.

his duties. For this purpose, a form of clock, called a watchman's time-detector, is employed. Such a clock is shown in Fig. 223. Here a high-class clock is employed, generally of the eight-day type. Be-

sides driving the hands, the mechanism of the clock is employed to rotate a suitable dial, on which a sheet of paper is placed, means being provided for readily replacing one sheet by another when so desired. On this sheet a number of radial lines, representing the hours of the day, and, when so desired, the minutes and seconds, are drawn. The radial divisions are divided longitudinally into separate parts, representing the various stations the watchman is expected to visit. Each of these stations is provided with a separate marker, so that, when the watchman visits any distant station, and depresses a push-button at that station, there is recorded on one of the divisions marks that indicate the particular hour and minute during which he visited this particular station.

Operation of watchman's time detector.

In some forms of watchmen's clock, instead of making the record by the same battery current as that employed for sending the signal, this current is used only to close the contact of a relay, which throws a local battery into action. By these means, a better record is ensured.

How tampering with the record is prevented.

In order to prevent watchmen from tampering with the record, most clocks of this character are now provided with contacts that register the opening and closing of the clock door, thus preventing the watchman from replacing the true paper disk by a spurious disk, which has been marked by hand.

Self-winding electric clock.

In order to increase the length of time a clock will run without requiring the services of an attendant to wind it up, the plan has been adopted of causing a battery current to pass momentarily through an electro-magnet, that will properly move the winding mechanism. Various devices may be employed for

such apparatus. In the form represented in Fig. 224, the winding is effected by the attraction of the armature of the electro-magnet represented at the bottom of the figure. Impulses for this purpose are sent into the line at periods about five minutes apart. While such self-winding clock movements can be made to act properly, unless great care is taken they are apt to interfere with the accuracy of the clock as a timekeeper.

FIG. 224.—Electro-magnetic Self-winding Clock.

In a system of electric gas-lighting, a jet of gas is lighted by the passage of an electric spark through the jet after the gas has been turned on at the stop-cock. This spark is generally obtained from an induction or spark coil, placed in the circuit of a voltaic battery and contact points placed on the gas-burner. Gas-burners for electric gas-lighting may be so arranged that the gas must first be turned on

System of electric gas-lighting.

by hand, and then a spark passed through the issuing gas-jet; or a better method may be employed, in which a burner, such, for example, as that shown in Fig. 225, is employed. Here the pulling of a pendent chain, P, turns on the gas by the moving of a valve inside the burner. At the same time, a platinum contact, A, placed on the end of a movable arm, makes a wiping contact with another platinum contact at B, placed near the gas-jet. In this manner, the circuit of a spark coil and voltaic battery is suddenly made and broken. The extra current pro-

Ratchet electric gas-burner.

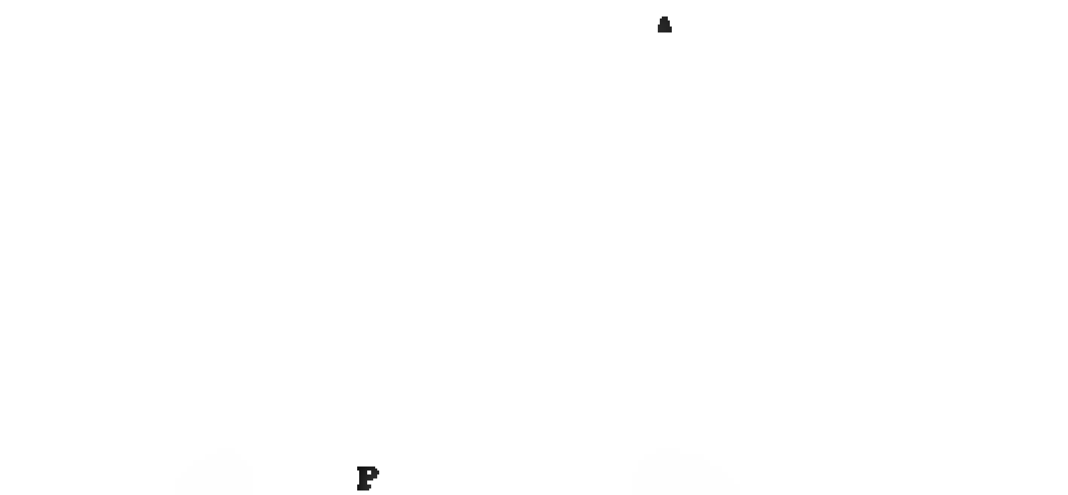


Fig. 225.—Ratchet Burner. Note that the pulling of the pendant P brings the contacts A and B together, and that on their separation a spark is produced which ignites the issuing gas-jet.

duced on breaking the contact produces a spark which jumps between the contacts at A and B, as they are suddenly separated, and thus lights the issuing gas-jet. When it is desired to turn off such a gas-jet, it is only necessary again to pull the pendant, since this motion now closes the valve and stops the flow of gas.

Automatic burner for electric gas-lighting.

In a form of burner called the automatic gas-burner, the gas is both turned on and lighted, and turned off and extinguished, by the motion of a push-button. The circuits for this purpose are gen-

erally so arranged that they control two separate electro-magnets. One of these magnets is excited by closing the circuit by the pushing of one of the buttons, generally a white one. The attraction of the armature of this electro-magnet turns on the gas, and, at the same time, causes a succession of sparks, produced from the spark coil, to pass through the issuing gas-jet and light it. On the pushing of another button, generally a black button, the circuit of the second electro-magnet is completed, which extinguishes the gas by closing the valve. An automatic gas-burner of this description is represented in Fig. 226, the separate electro-magnets being placed inside the cover.

Fig. 226.—Automatic Electric Gas-lighting Burner.

Battery protector for system of electric gas-lighting.

Systems of gas-lighting are operated on open circuits. Considerable trouble is experienced in the use of such systems, from the liability that exists of accidental contacts rapidly running down the strength of the battery by polarization. In order to avoid this difficulty, an arrangement is frequently made by which the wires in the house are divided into a number of separate circuits, and these circuits are so connected with an apparatus called a battery protector, that on any accidental short circuit occurring in any one of these separate circuits, an electro-magnet is energized, and that particular circuit automatically cut off from the battery. A battery

protector can be combined with an annunciator, the arrangements being such that, on the accidental closing of any one of the circuits, this circuit is auto-

FIG. 227.—Automatic Annunciator for Battery Protector.

matically disconnected from the battery, and a drop is caused to fall on the annunciator board, indicating the particular circuit that has thus been disconnected. A device of this character is represented in Fig. 227.

V

ELECTRIC HEATING

CHAPTER XXVII

ELECTRIC HEATING OF BARE AND COVERED CONDUCTORS

"I know not where is that Promethean heat."
—*Othello,* Act V, Scene II

A DEFINITE quantity of work must be done or energy expended in order to raise the temperature of a pound of water, or any other kind of ordinary matter, through say one degree of the thermometric scale. As in all other cases of work done or energy expended, this energy is capable of being expressed in foot-pounds or in joules. In the case of water, in order to increase the temperature of one pound of water one degree Fahrenheit, there must be expended on the water, in order to set the molecules into the to-and-fro vibrations that produce heat, an amount of work equal to 778 foot-pounds, or the work required to raise 778 pounds through a vertical distance of one foot. Since the joule is equal to 0.738 foot-pounds, this would be nearly equal to one pound raised through a vertical distance of nine inches. There would, therefore, require to be expended to raise the temperature of the water, as above indicated, an amount of work equal to 778 foot-pounds divided by 0.738, or 1, 055 joules.

Relation existing between mechanical and heat energy

Joules and foot-pounds.

The amount of work that is required to increase the temperature of the water is perfectly definite:

778 foot-pounds, or 1,055 joules, will increase the temperature of one pound of water just one degree F., neither more nor less. This, of course, is on the supposition that all the energy is expended in producing heat. No matter what may be the origin of the work or energy that is thus expended, whether it be mechanical, chemical, electrical, or magnetic, 778 foot-pounds, or 1,055 joules, must be expended in order to perform the work required to raise the temperature of one pound of water through one degree F.

Since all heated bodies impart their heat to the air or other medium surrounding them, if a given temperature is to be maintained in the heated body, there must, of course, be a constant expenditure of energy. The rate at which energy must be expended for this purpose, that is, the activity as it is called, can be expressed in foot-pounds per second, or in joules per second, or in watts, the watt being a rate of doing work that is equal to 0.738 foot-pounds per second. The activity or rate at which a given amount of water escaping from a reservoir is capable of doing work, such, for example, as raising the temperature of a given mass of water, depends on the quantity of water which escapes per second, and on the distance through which it passes in order to escape. As we have already seen, there is a similarity in the case of a given quantity of electricity flowing from a battery, dynamo or other electric source, and water escaping from a reservoir. The activity of the electric source, or the rate at which it is capable of doing work, is equal to the quantity of electricity that escapes per second multiplied by the difference in the level through which it passes in order to escape. In other words, the coulombs of electricity that pass, multi-

Joules per second or watts.

plied by the difference of electric level or pressure through which they pass, in volts, give a quantity which represents the electrical activity. In other words, the activity of an electric source can be expressed in joules-per-second, that is, in watts. Now, as we have already seen, an ampère is equal to a coulomb per second, and since a watt is a volt-ampère, it is evident that if we multiply the coulombs-per-second by the volts, we will get an expression for the watts. Since the watt is a very small quantity, being equal only to the $\frac{1}{746}$ of a horse-power, it is convenient, in practice, to employ a larger unit of electric power; *i.e.*, the kilowatt, or a thousand watts. Since 746 watts equal one horse-power, it is evident that there will be in 1,000 watts 1,000 divided by 746, or about 1.34 horse-power. If, therefore, we know the E.M.F. that is driving the electric current through a conductor, and we know, moreover, the value of the current that is passing through the circuit, the product of these quantities will be equal to the activity of that circuit per second.

A unit of electric power—the kilowatt or 1,000 watts.

In order to determine by experiment the amount of heat that will be imparted to a given quantity of water by the passage of an electric current through it for a given time, an instrument called an electric calorimeter may be employed, as was done by both Joule and Lenz. Here a thin wire, N M, Fig. 228, of known electric resistance, is placed in a glass vessel containing a given quantity of water or other liquid. A thermometer, T, placed in the vessel in the manner shown, gives the temperature of the liquid, both before the current is passed, and after the current has been passing through the liquid for a definite time. It can be shown by experiments that the increase in temperature of the water or other

Electric calorimeter

Circumstances determining the temperature produced by the passage of an electric current through any circuit.

liquid so produced by the passage of the current is proportional to the resistance of the conductor, to the square of the current strength that is passing in ampères, and to the time during which the current has continued to pass.

Heat developed in circuit dependent on the square of the current passing.

Since a difference of pressure or E.M.F. is necessary in order to cause a current to flow through a conductor of a given resistance, this fact, thus demonstrated by experiment, is only another way of stating that the passage of a current in ampères, while under the influence of a given pressure or

FIG. 228.—Electric Calorimeter. Note that the instrument readily permits the increase in temperature of the water in M, produced by the passage of the current for a certain time, to be determined by the thermometer T.

E.M.F., in volts, will produce a given rise in temperature, because there is thus expended in the circuit a given number of watts-per-second. A difficulty is often experienced in understanding why the heat developed by a current is proportional to the square of the current, and not simply proportional to the current itself. Silvanus P. Thompson, in his work on "Electricity and Magnetism," thus remarks concerning this fact:

Silvanus P. Thompson on the heat developed by an electric current.

"The second of the above laws, that the heat is, *cæteris paribus* (other things being equal), propor-

tional to the square of the strength of the current, often puzzles young students, who expect the heat to be proportional to the current simply. Such may remember that the consumption of zinc is, *cæteris paribus,* also proportional to the square of the current; for, suppose that in working through a high resistance (so as to get all the heat developed outside the battery) we double the current by doubling the number of battery cells, there will be twice as much zinc consumed as before in each cell, and as there are twice as many cells as at first the consumption of zinc is four times as great as before."

Another method of looking at this question is, perhaps, simpler to those who are able to employ a little easy mathematics. Bearing in mind that the heat generated is proportional to the number of watts expended in causing the current to flow through the circuit, or to $C \times E$, the product of the current in ampères, multiplied by the E.M.F. in volts, and remembering also that by Ohm's law the current in ampères is $C = \frac{E}{R}$, it follows that E equals $C \times R$. Consequently, placing the value of $E = C \times R$ in equation, $C \times E$ equals the watts, we get $C \times CR =$ the watts, or $C^2R =$ the watts. In other words, the power required to overcome the resistance of the wire is equal to the square of the current multiplied by the resistance. This, of course, is only true where the value of the resistance remains constant. **Another way of explaining the C and R law.**

When a given E.M.F. is applied to a circuit in order to cause a current to flow through such circuit, and thus overcome its resistance, a certain drop of pressure or loss of E.M.F. results. Suppose that, in the case of a given conductor or wire, this drop be 10 volts, and that a current flow **Drop of pressure or loss of E. M. F. in current flowing through conductor.**

through the conductor equal to 100 ampères. Then it can be shown that the number of watts that will be developed in such a circuit will be equal to the drop of 10 volts multiplied by the current strength in ampères. In other words, the heat activity that will be developed in the circuit will be equal to the product of the drop in volts multiplied by the current strength in ampères, or $10 \times 100 = 1{,}000$ watts, or 1 K.W. If, therefore, we know the drop of pressure that occurs in any circuit, and the current strength that is passing in that circuit, it will only be necessary to multiply the two quantities together in order to obtain the heat activity in watts, or the amount of heat that will be liberated in the wire during every second of time.

Temperature produced by the passage of an electric current through a conductor.

Let us now inquire as to the temperature that will be imparted to a given wire or conductor through which such current is passing. Since the current is supplying the heat to the wire at a constant rate, the temperature of the wire will steadily increase. At the same time, however, the wire is giving off its heat to the air or other medium surrounding it. Moreover, the amount of this loss will increase the greater the difference of temperature between the wire and the surrounding medium. Consequently, a point will soon be reached when the amount of heat imparted to the wire by the electric current will exactly balance that imparted by the wire to the medium surrounding it. At this point the temperature of the heated wire will remain constant or steady.

A heated wire or conductor can give off its heat to the air or other medium surrounding it in three different ways. In the first place, the air or other medium can take away the heat from the wire by

conduction. This will be especially the case in any underground cable, where the conductor is surrounded by some insulating material placed within a lead sheath or covering. Where the wire is surrounded by air or water, the differences of temperature set up currents in the air or water, called convection currents, whereby the heat is rapidly carried away from the conductor; for the cooler portions of the air are constantly being brought into contact with the surface of the heated conductor. Besides the loss of heat by conduction and convection, there is an additional method; viz., by radiation, by which the heated conductor can give its heat energy to the medium surrounding it. In radiation, the heat passes off from the hot body in all directions, just as in an incandescent lamp both heat and light are radiated or given off by the glowing filament.

How a heated wire or conductor can lose its heat.

Conduction, convection, and radiation.

It will be evident that the temperature which a wire or conductor will attain will depend on the rapidity with which it is able to lose the heat imparted to it by the electric current in one or another of these three different ways. It will, evidently, also depend on the condition of the wire as to whether it is bare or covered.

Temperature elevation.

In the case of the loss of heat by radiation, the ability of the wire to give off its heat will also depend on a number of different circumstances, such, for example, as the dimensions of the wire, which determine the extent of the radiating surface. It will also greatly depend on the character of the surface, whether it be rough or smooth, polished or dull, a rough, unpolished surface losing its heat much more rapidly than a smooth or polished surface.

Conditions influencing radiant losses.

But there is evidently a still more important cir-

cumstance that determines the temperature to which a given current strength may be able to raise a wire or conductor, and this is on the value of its resistance per unit of length. The passage of a given current strength through a given resistance will result in the liberation of a certain quantity of heat, but so far as the temperature elevation is concerned, it is evident that, since a short, thin piece of wire of a certain substance may have the same electric resistance as a long, stout wire of some other conducting substance, the liberation of the same quantity of heat in these two different conductors will necessarily result in a far higher temperature for the small, thin conductor than for the long, thick conductor, and this is especially the case since the surfaces from which the conductor loses its heat are much greater in the latter than in the former case.

Influence of resistance on temperature elevation.

For this reason, where it is desired that a high temperature elevation shall be produced by the passage of a given current strength, as in the case of electric heaters, it is only necessary to employ a comparatively short conductor of small diameter, composed of a substance whose power of conducting per unit of length is comparatively small. Of course, all electric energy converted into heat energy ceases to be of value as electric energy. Consequently, in the case of a transmission circuit, where electric energy is generated at one end of the line, and is to be employed at the other end, care must be taken to lose as little of the energy during transit as possible. For this purpose, good conductors are required to be employed, between the electric source and the electric heater, so that the resistance to be overcome shall be as small as convenient. Moreover, their area of cross-section is increased up to certain limits.

Necessity for high conducting power in transmission circuits.

In most of the cases of electric transmission of current, the reason for keeping the resistance as low as possible will be evident, since the lower the resistance, the smaller will be the drop of pressure in the circuit, and, consequently, the smaller the loss of energy from the conversion of electric into heat energy. In the next place, as the temperature of the wire or conductor increases, its resistance increases, and, consequently, the loss during transmission increases. Finally, in nearly all cases, it is dangerous to permit the temperature of the conductors to increase beyond a certain limit, since too high a temperature of the conducting wire may produce damage from fire.

Why the resistance of transmission circuits should be kept low.

The current strength that can be safely permitted to pass through a given wire or conductor is sometimes regarded as that current strength which will not increase the temperature of the wire beyond that at which the wire can be grasped in the hand for one minute without inconvenience. The limit of temperature, however, will necessarily vary according to the location of the wire and its surroundings. In the case of an underground wire placed in a terra-cotta conduit, a much higher temperature may be safely imparted to the wire than in the case of a conductor passing through wooden molding. But even though in the terra-cotta conduit an increase in temperature might safely be permitted so far as the conduit itself is concerned, yet it is clear that there will be a limit here which will be reached when the temperature will begin to injure the character of the india-rubber, gutta-percha, or other insulation employed, which, as is well known, is injuriously affected by a high temperature. Moreover, in the case of an underground conduit, a danger might exist from the tendency of an overheated conductor

Safe limiting temperature for transmission circuits.

to explode the mixture of illuminating and sewer gas that is apt to be found in underground conductors that pass through the streets of large cities.

Time required for conductor to acquire the full or steady temperature.

The time required for a wire to attain its steady or full temperature after the full-load current has been passed through it will, as we have seen, depend on the character and position of the wire. In the case of a wire suspended in the air, it will acquire within 95 per cent of its full temperature some two minutes after the full-load current has been applied to its terminals. If immersed in water, the wire will require a much longer time, some ten minutes being required for this purpose. Wires running through wooden moldings do not reach their full temperature until some fifteen minutes after the full current strength has been passed through them, while wires buried in the ground may require as long as twenty minutes before reaching their full temperature.

CHAPTER XXVIII

FUSE WIRES

"The search for a satisfactory fuse metal seems now to be directed toward such metals as aluminium, cadmium, tin, zinc, and those of a similar nature, or their alloys. A simple metal is, however, more desirable for this purpose, unless the alloy possesses features which can not be obtained otherwise. Since the desired metal must be cheap, aluminium and zinc at once become most attractive. Both possess the desired conductivity, and melting point, and their vapors have the desired high-resistance property which is, no doubt, due to their extremely rapid oxidation."—*Fuse Protective Devices:* SACHS

IN the early history of the art it was believed that the introduction of electric lighting into houses would necessarily be limited by the fire risks arising from the accidental passage of heavy currents of electricity through the conducting wires raising them to bright incandescence. Such fears, however, have not been realized in actual practice, since careful wiring, together with the employment of the exceedingly simple and well-known electro-thermal safety device called the safety fuse or safety catch has entirely removed all such danger. This protection, however, is only ensured when certain precautions of construction, etc., are taken.

No increased fire risks from electric lighting circuits if properly installed and protected.

A safety fuse or safety catch, as its name indicates, consists of a strip, bar, or plate of some readily fusible alloy or metal, that will automatically fuse on the passage of an abnormal current strength, which might otherwise dangerously affect the rest of the circuit. There are a number of substances that may be employed as a material for safety fuses. They must, however, all possess a higher resistance

Safety fuses or catches.

per unit of length than that of which the rest of the circuit is formed; and, moreover, they should have a low point of fusion. If the material of which the fuse wire is composed is such that a short thin piece in the form of a wire or conductor has a resistance much greater than that of an equal length of the rest of the circuit, the passage of a current will develop in the fuse wire so much heat in a small space that it will acquire a temperature sufficiently high to fuse the wire, and thus automatically break the circuit. It will be impossible, therefore, under these circumstances, for a dangerous current to exist for any time on the circuit. It is a fortunate circumstance that so simple a device is capable of acting in so satisfactory a manner. The materials generally employed for safety fuses consist of alloys of lead and tin, these alloys varying in proportion from 33⅓ per cent to 80 per cent of lead.

General action of safety fuse.

It is customary to insert safety fuses at all points in circuits where the wires decrease in size, the fuse being inserted in the circuit of the smaller wire. Short pieces of cylindrical fuse wire are employed for such purposes, the ends of the wires being wrapped around suitable binding posts. Frequently, however, in order to ensure a better contact of the safety fuse wire to the circuit, the fuse wires are replaced by strips of fusible alloy, that are soldered to two copper terminals. These terminals are provided with slots for the ready insertion of the fuse in the circuit. Such a form of fuse is generally styled a fuse link, in order to distinguish it from a simple fuse wire. Several forms of fuse links are represented in Fig. 229.

Safety fuse-links.

Since, when a fuse wire melts or blows, it may scatter the molten globules in all directions, it is necessary to enclose the wire in a box of porcelain, or

some other incombustible material. Such blocks are called fuse blocks. Where powerful currents are employed, in order to prevent a voltaic arc from

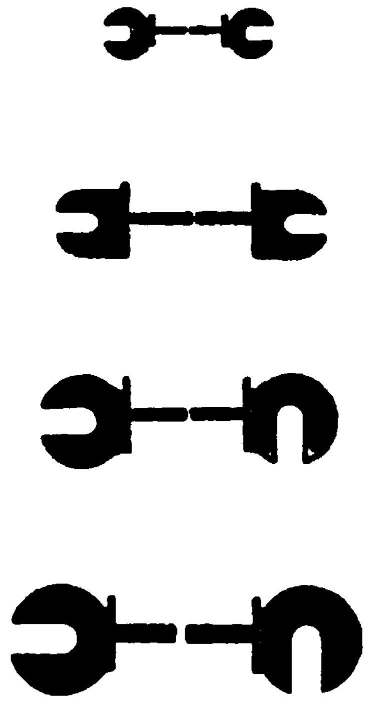


FIG. 229.—Safety Fuse Link. Note the U-shaped terminals provided for ensuring the ready insertion of link in circuit to be protected.

being formed across two contiguous conductors on both of which fuse wires are placed, the fuse block is provided with a ridge for the purpose of separating these two parts of the circuit from one another.

Necessity for employment of enclosed fuses.

FIG. 230.—Enclosed Safety Fuse in Porcelain Block. Note the spaces provided for the two main conductors with the separating porcelain ridge R, R.

A fuse block, provided with a porcelain ridge, is represented in Fig. 230, where two separate fuse wires are shown as connected to two branches of the circuit, these two being separated from each

other by the ridge of porcelain shown in the figure. When such a porcelain block is provided with its cover, the two circuits are completely isolated from each other.

Fig. 231.—Enclosed Fuse Wire for Electric Motor.

Enclosed fuse for electric motor.

A form of fuse or cut-out, provided for the protection of an electric motor, is shown in Fig. 231. Here a fuse wire, cylindrical in shape, is placed in a channel formed in the cover of the box. This position of the fuse wire possesses the advantage of permitting it to be safely replaced without danger from the current. In addition, the curved shape of the channel renders the formation of the arc on the blowing of the fuse much less likely to occur.

Fig. 232.—Edison Fuse Plug for Base of Incandescent Electric Lamp.

Edison enclosed fuse wire.

The enclosed fuse was first introduced into the art by Edison in the form of the fuse wire or plug placed in the base of his incandescent lamp, as represented in Fig. 232. Edison patented the enclosed fuse wire on May 4, 1880. The construction here shown possesses the advantage that the mere intro-

duction of the lamp into its socket places the fuse wire in the circuit. Such a form of cut-out is generally called a plug cut-out.

In addition to enclosing the safety wire in a protecting covering or sheath, it has been found necessary, in order to ensure the greatest safety, to surround the fuse wire by a jacket or sheathing filled with some porous or other similar material, such as chalk. Such a fuse wire is called a cartridge fuse. It differs from an enclosed fuse in that the latter may only contain air. Where a fuse is enclosed in a space that is filled with air only, when the fuse wire is blown, an abnormal increase in the air pressure in the enclosed tube is produced by the heating, and consequent expansion, of the enclosed air. This may be sufficient to produce an explosion of the fuse box, and a scattering of the molten fuse metal. When, however, the fuse wire is surrounded by such a material as powdered chalk, the enclosed gases, instead of rapidly expanding, pass through the mass of the enclosing material and rapidly give up their heat to the same. The fuse box, however, must not be too tightly packed with this material, since that might result in the molten metal being held in position, and thus failing to break the circuit the fuse was designed to protect. This may be avoided by not packing the box so tightly with the material, and affording spaces through which the expanded air may be permitted to escape. Asbestos has been successfully employed as a packing material.

Difference between cartridge fuses and ordinary enclosed fuses.

Why enclosed fuses sometimes fail to operate.

The necessity for enclosing the safety fuse is thus explained by Joseph Sachs, in a paper read before the American Institute of Electrical Engineers, March 28, 1900:

Sachs on enclosed fuse wires.

"Notwithstanding the many statements to the contrary, no similar electrical device is based on

simpler, or even as simple, operating principles as the thermal cut-out, as it may properly be called. The generation of heat in any current-carrying conductor is a well understood phenomenon. The rise of temperature in this conductor, due to the heat energy imparted to it, is governed by well-known conditions. If these conditions could be made fixed instead of constantly varying quantities, accuracy and certainty of action would result.

Temperature elevation of conductor.

"The heat energy imparted to a section of conductor by a certain current flowing for a definite time is a fixed quantity. The temperature attained in this conductor depends simply on how much of this heat energy is thrown from the conductor during that particular time interval. It is entirely obvious, even without the various experimental investigations on this point, that any condition that varies the amount of heat energy taken from the conductor, varies the temperature attained, and hence the carrying capacity of the conductor, since the melting of the metal is dependent thereon. The several ways in which this heat is dissipated from the ordinary air-exposed fuse conductor is entirely familiar to all electrical engineers, but fuses always have been, and are now, and in the case of open-air fuses probably always will be, used indiscriminately without regard to these simple facts, and yet constancy and accuracy are expected.

Dangers of the air-exposed fuse.

"Perhaps even more serious, however, than accuracy is the lack of safety in the ordinary exposed fuse. On this score a multitude of transgressions are heaped up against fuse devices of such types as have been in use a dozen years on nearly all classes of high and low voltage services. No exposed fuse is safe (considered from the standpoint of fire hazard to its surroundings). The destructive and dangerous arcing of all exposed fuses when ruptured

by excess current, and particularly short-circuit conditions at the higher potential, must be entirely and not partially eliminated before the fusible cut-out can be considered a perfectly satisfactory protective device. Even when a fireproof housing is provided, safety is not absolutely assured. This serious objection to all open fuses is becoming more rather than less serious in its aspects in view of the introduction of higher potentials and enormous generating capacities.

"Aside from the shortcoming already stated, air-surrounded fuses have other failings, prominently among which is the oxidation of the metal when subjected to heat, to which probably as much of the unreliability of such fuses may be attributed as to the conditions already stated. The formation of an enclosing envelope of oxide around the commonly used lead-tin alloy fuse wire is in many instances sufficient to hold the metal in a molten condition. The effect of such a condition is entirely obvious and well appreciated. The ease with which the cross-section of exposed fuses may be decreased by accident or otherwise; the position of the fuse, whether vertical or horizontal, the straight or irregular arrangement of the strip between its terminals, and the contact between the fuse and circuit contacts: all have their effects on the carrying capacity and are deficiencies well understood and thoroughly appreciated. It is true that the use of a strip of fuse wire between terminals of better conducting metal would partially eliminate some of these bad features if an absolutely standard length between contact posts or screws were assured, but the loose practice of the past did not indicate any appreciation of the fact that any piece of porcelain having several brass stampings or castings mounted upon it is not necessarily a safe and accurate mounting for the simple

Why enclosed fuses sometimes fail to open a circuit.

Necessity for care in construction and placing of fuse wires.

yet delicate device whose exactness of operation can only be arrived at by definitely fixing all the conditions upon which its action depends."

Some of the requirements of efficient safety fuses

Considerable inconvenience may result from a fuse blowing at too slight an increase in the current strength beyond that which the circuit is intended normally to carry. In order to avoid this, it is quite common to employ fuses on the circuit whose carrying capacity varies from 30 to 50 per cent beyond that of the current of full load. It is not an easy matter, however, to obtain a fuse metal or alloy that will promptly blow or fuse, under all conditions, as soon as the current strength in the circuit has reached the predetermined point. In the first place, it appears that occasionally changes occur in the character of the alloy, which produce slight changes in its point of fusion. Then, again, the fused metal may remain for some time in a condition in which it is capable of conducting the current before an absolute volatilization or blowing of the fuse occurs, which will ensure the breaking of the circuit. In order, however, for any fuse to ensure safety to the circuit in which it is placed, it should act promptly, and should possess the same fairly low fusing point when first placed on the circuit as it does at a much later time. Moreover, arrangements should be made so that the permanency of the contacts are ensured. C. P. Matthews, in a paper on "Fuse Metals," read before the American Institute of Electrical Engineers, remarks as follows on some of these points:

Matthews on promptness of action of safety fuse.

"Promptness of action requires that the temperature of fusion should not be too far removed from that attained when the wire is being worked at its rated capacity. Moreover, it is important that the metal should not undergo chemical changes produced by the action of the heat, which may appre-

ciably alter its melting point. The formation of oxides may or may not promote prompt fusion. In the case of pure tin and some of its alloys, a coating of oxide is often formed which retains the molten metal some time after the temperature of fusion has been passed, ultimate rupture usually occurring with considerable violence. On the contrary, the rapid oxidation of iron and copper wires seems to favor prompt fusion.

"The question of low fusing point is one with which the fire underwriters are concerned, since wires fusing at high temperatures introduce an element of danger from fire. With fuses enclosed in properly constructed blocks, the danger from this source is not great, and the necessity of employing a metal of low melting point is not so important as might be imagined. Experience shows that fuses made of nearly all the metals available for such purpose will melt without dangerous scattering of particles or liberation of hot gases, when the current is gradually increased until the break occurs. This, however, is a condition which rarely obtains in practice."

Advantages of low fusing point of fuse metals or alloys.

It has been observed in practice that at times the position of a fuse wire apparently influences the temperature at which it will fuse and automatically break the circuit. For example, some fuse wires in a horizontal position apparently possess a higher temperature of fusion than in a vertical position. A little thought, however, will show that this is not, in reality, the case, the true explanation being that, when a vertically placed fuse wire melts, the metal instantly runs, and thus tends to break the circuit, while, in the case of a horizontally placed wire, the liquid metal may remain for some time in place, and thus afford a conducting path, giving the

Failure of melted fuse wire to break circuit.

impression that the fuse has not melted. Of course, it would be possible, should such be desired, to employ a blow-out magnet for ensuring the separation of the molten metal on the passage of a dangerous current, thus ensuring the separation of an important fuse in any system of distribution. In a cartridge fuse, where, as already pointed out, the material placed inside the fuse box entirely surrounds the fuse wire, the automatic breaking of the fuse may readily be interfered with. Where, however, the temperature of the fuse was so suddenly and greatly increased as to produce a true deflagration of the fuse metal, the vapors that are thus suddenly liberated would, in most cases, be sufficient to scatter the particles in all directions.

Suggested use of a blow-out magnet.

At a National Conference on Standard Electrical Rules, held in New York City, March 18 and 19, 1896, the following rules were adopted. They will be interesting as indicating the view then generally held. According to these rules fuse wires:

Rules on fuse wires adopted by National Conference of 1896.

"*a.* Must have contact surfaces or tips of harder metal having perfect electrical connection with the fusible part of the strip.

"*b.* Must be stamped with about eighty per cent of the maximum current they can carry indefinitely, thus allowing about twenty-five per cent overload before fuse melts.

"With naked open fuses, of ordinary shapes and not over 500 ampères capacity, the maximum current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

"Enclosed fuses, where the fuse is often in contact with substances having good conductivity to heat,

and often of considerable volume, require a much longer time to reach a maximum temperature on account of the surrounding material which heats up slowly.

Fuse terminals must bear maker's name or other mark.

"*c*. Fuse terminals must be stamped with the maker's name, initials, or some known trademark."

CHAPTER XXIX

ELECTRIC HEATERS

"And then to breakfast with
What appetite you have."
—*King Henry VIII,* Act III, Scene II

THE electric heater is a device whereby the energy of an electric current is caused to expend itself in raising the temperature of a conductor, under circumstances which permit such conductor readily to give up its heat to the air or other medium surrounding it. Electric heaters possess many points of advantage over other methods for the artificial production of heat. In the first place, the time required for a conductor to acquire its maximum temperature after a full-load current has been applied to its terminals, is quite small, being only a few minutes at the most. Then, in the next place, the efficiency of an electric heater is extremely high, in fact, higher than that of any other electric device. Practically all the energy present in an electric current is capable of being converted into heat energy, so that the efficiency of an electric heater can be made practically equal to unity.

Some of the advantages possessed by electric heaters.

As far as the amount of heat energy that can be obtained from a pound of coal or other fuel is concerned, the ordinary method of causing it to give up its energy as heat in the common fire or stove must evidently be far more economical than any method for first converting this energy into mechanical motion, then into electric energy, and, finally,

into heat energy; for, in all such cases, there is necessarily a great loss in the numerous transformations that occur. In the first place, only a part of the heat is transferred from the fire under the boilers to the water in the boilers. In the second place, a loss occurs in transforming the heat energy in the steam into the mechanical energy of the steam engine. Then, again, another loss occurs in the transformation of the mechanical energy into electric energy; while still another loss occurs in carrying the electric energy from the generator to the points where the electric heaters are situated. It is not probable, therefore, where the heat energy is derived through the intervention of a steam engine, that electric heaters will ever be employed for the heating of large buildings, or even possibly for the heating of houses, during such parts of the year that considerable heat is required to be developed continuously. In the case of cheap water power, a different state of affairs might readily exist.

Some necessary losses that occur in the ordinary production of heat energy by electricity.

There are circumstances, however, under which electric current, even when obtained from steam engines, can be economically employed to-day for electric heating. Wherever a comparatively small quantity of heat is required for but a limited time, the ease with which an electric heater can be turned on or off, and the small bulk which it can be made to occupy, enable it successfully to compete with the ordinary stove. For example, suppose it be required to make a cup of coffee; instead of building a fire in a range or cooking stove capable of cooking an entire dinner, merely for the purpose of boiling the small quantity of water required in making the coffee, an electric heater can be employed, occupying an exceedingly limited space, an electric current can be turned through its coils, which acquire their full

The electric stove or heater *vs.* the ordinary coal fire.

temperature in a few minutes, and as soon as the boiling of the water is completed, which in all will require but a short time, the current can be turned off, and thus a further expenditure of energy saved; while, in the case of the stove, the fire must practically burn itself out.

An advantage of the electric heater.

Then, too, the occasional heating of a room, such as a bathroom or breakfast-room, for a half-hour or so, during parts of the year when the weather is not very cold, can be more conveniently, and, indeed, even as economically, effected by electric heating as by the heating of a heater or by a hot water system.

Advantages possessed by electric heaters.

The many conveniences possessed by electric heating over ordinary heating have naturally caused it to increase during the past few decades. This is especially the case where systems of incandescent lighting are employed. The small space in which an electric heater is capable of being placed, and the readiness with which it can be moved about, give to it advantages which will appear more evident when we come to discuss some of the many practical applications of this system of artificial heating.

Electric heaters *vs.* gas or oil heaters.

Before proceeding to the discussion of the many applications of electric heaters, it may be well at this point to call attention to the fact that the advantages claimed for the electric heater, so far as the ability to start and stop the heater is concerned, apply with equal force to the case of ordinary heating by gas or oil. There is, however, this fact in favor of electric heating; *viz.*, in the case of heating by gas or oil, the products of combustion tend to vitiate the air of the room in which the heating is carried on, unless, of course, a chimney is provided; while, in the case of electric heating, this objection is entirely

removed, since the electric heater in no way vitiates the air of the room in which the heating is taking place.

Construction of electric heater.

The electric heater for heating the air of a room or car is of exceedingly simple construction. It is formed of a coil or circuit of some refractory material, such, for example, as galvanized iron or German silver wire. This conductor is placed in the form of a loose coil, so as to ensure a fairly considerable extent of radiating surface, and thus enable the coil to rapidly impart its heat to the surrounding air. The contiguous turns of the coil, however, are

FIG. 233.— Electric Street-car Heater. Note the extreme simplicity of construction of this form of car heater.

sufficiently far apart to permit the ready access of air on all sides. In order to prevent contiguous coils from coming into contact with one another through a change of form when the temperature is high, the heating coils are wound in grooves in the surface of a block of earthenware, porcelain, or other similar material that is neither inflammable nor a conductor of electricity.

An electric heater, suitable for heating the interior of a street car, is shown in Fig. 233. Here a cylindrical porcelain tube is provided with spiral grooves for the reception of the heating conductor. The heating coils are placed inside a heater box formed of a case of sheet-iron, and covered on the

inside with asbestos or some other substance that prevents an overheating of the heater case.

Electric heaters for street cars.

The electric street car affords an especially favorable opportunity for efficient electric heating. Heaters for this purpose are placed generally in sets of four or six separate heaters on the sides of the car, directly under the seats. In order to protect the passengers from being burned by accidental contact with the heating surfaces, the heaters are placed in-

FIG. 234.—Street-car Heater. Note the greatly increased radiating surface of the heater wire, obtained by coiling a wire as represented.

side a box provided with a suitably arranged grating. The current for the purpose is, of course, taken directly from the driving and lighting current of the cars. Various forms of electric street-car heaters have been devised.

American street-car heater.

In some cases, for the purpose of increasing the extent of the radiating surface of the heaters, the coils, instead of being formed of a single, straight wire, as represented on the preceding page,

QUEEN ALEXANDRA'S LAMP, FINSEN LIGHT CURE

Dr. Neils Finsen discovered that the chemical rays of light destroy certain disease germs. A powerful electric light is the usual source of these rays. In the picture, a cure for lupus is being effected under the lamp presented by Queen Alexandra to the London Hospital

is itself coiled around a stout asbestos cord, and the coils are formed of this coiled wire, the coils being loosely supported on porcelain insulators in the manner shown in Fig. 234, where B represents the asbestos cord and A the heater wire or conductor. The coiled wire is supported on a light steel frame, C, provided on both of its sides with porcelain insulators, D, for the support of the coiled wire. The ends of the heater coils pass out of the heater case through porcelain insulators, as shown at the right-hand side of the figure. A metallic grating is placed in front of the heater case, as already mentioned.

FIG. 235.—Heat Regulating Switch for Electric-car Heaters.

Heat-regulating switch for electric-car heaters.

In the case of the electric car-heaters, there is always provided some form of switch, by means of which the separate heaters can be readily connected either in series or in parallel, or some of the heaters can be cut out from the circuit, thus readily permitting a difference of temperature that will keep the car comfortably warm during marked differences in the outside temperature. A switch for this purpose is shown in Fig. 235. Here the movements of the switch handle cause an index pointer, or finger,

to move over the scale represented in the figure. When the pointer is opposite the figures 1, 2, and 3, the connections are such that the greatest amount of heat will be liberated in the position 3, and the least amount of heat in the position 1; 2, corresponding to an intermediate degree of heat. Various groupings of a number of heater coils are possible for this purpose. It may be generally stated, however, that when all the coils are in series, since the current is supplied from constant-potential mains, a smaller quantity of current will pass, and,

Various groupings of heater coils possible.

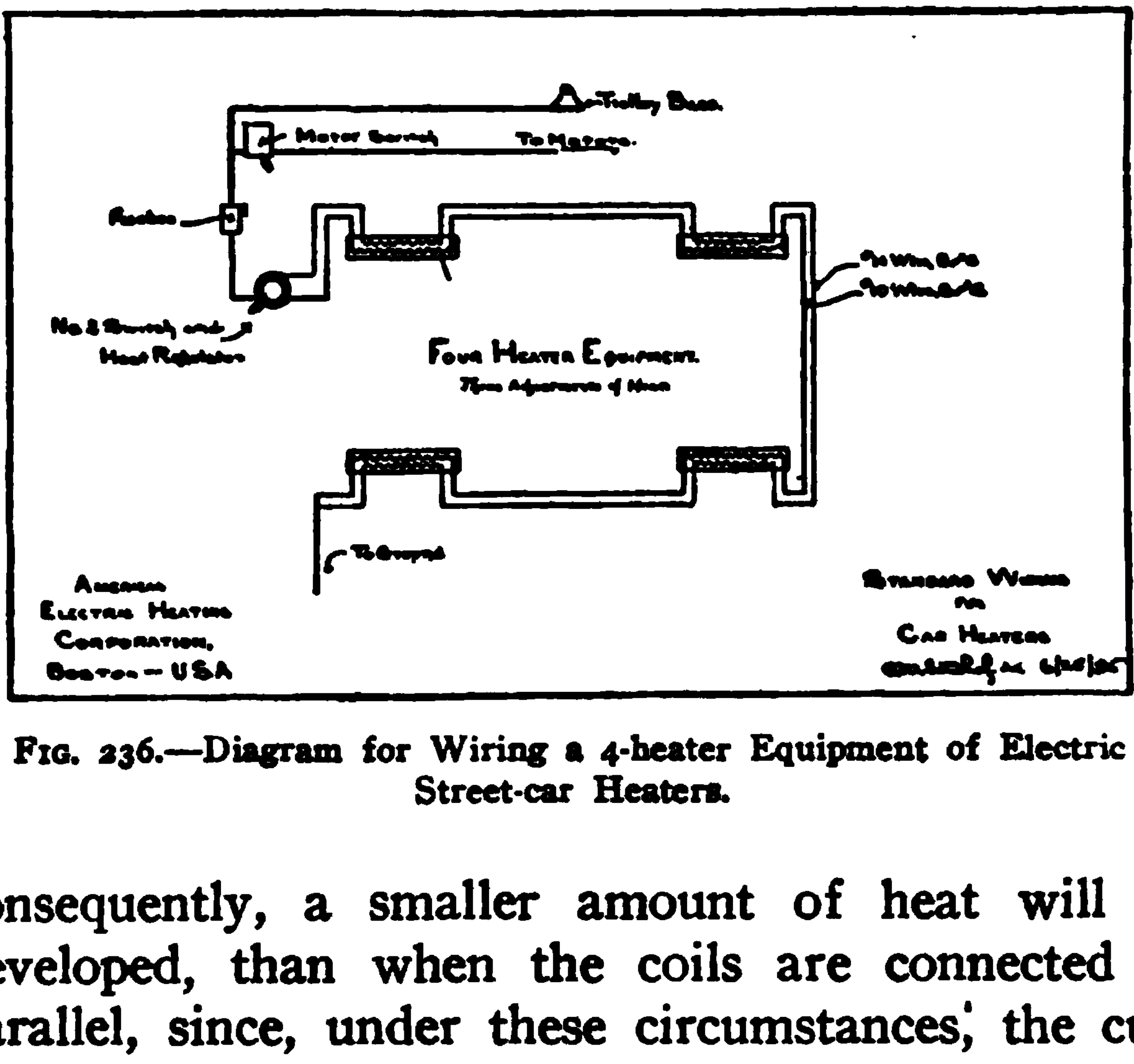


FIG. 236.—Diagram for Wiring a 4-heater Equipment of Electric Street-car Heaters.

consequently, a smaller amount of heat will be developed, than when the coils are connected in parallel, since, under these circumstances, the current strength will greatly increase, and, consequently, the amount of heat developed will also increase.

The connections of a four-heater car equipment for one of these positions is shown in Fig. 236. Here, as will be seen, the heaters are inserted between the trolley wire or conductor and the ground.

The heat-regulating switch is placed directly between the fuse box and the heater coils.

In some forms of car heaters, instead of surrounding the heater wire by air, the wire is imbedded in an enamel, that has been fused on the surface of an iron plate. In this manner the heater wire is protected from injury from moisture or corrosive agents. Moreover, a greatly increased surface is provided for the radiation of heat. A street-car heater of this type is shown in Fig. 237.

Enamel-covered electric street-car heater.

FIG. 237.—American Enamel Car Heater. The lugs at the side are for attaching the heater to the side of the car.

The cost of heating cars by electricity will, of course, depend on the cost of producing the electric current, and will vary greatly with the size of the car and the climate in which the system is operated. It has been stated, however, as a result of actual trials, that the average cost of heating a standard trolley car by electricity during the winter in the northern parts of the Atlantic States is equal to about 2¼ cents per hour, or 40.5 per day of 18 hours. Other estimates place this cost as low as 25 cents per day. No trouble has been experienced in a climate as severe as that of Boston, Mass., during severe winter weather. Here, by actual measurements, the temperature of the air inside an ordinary trolley car, containing 850 cubic feet of air space, was readily maintained at a temperature of 25° F. above the external air by the use of the usual electric heaters.

Cost of car heating.

Although the above cost is somewhat greater than the cost of heating by oil or coal, yet it must not be forgotten that the system of electric heating for such purposes is superior, so far as ventilation and convenience to the passengers are concerned, to any other method of artificial heating. Moreover, since the electric heaters are placed underneath the car seats, and, therefore, require no space that is available for passengers, there is probably saved, in the case of cars heated electrically, a space that could accommodate say two additional passengers. From this standpoint, therefore, it would appear to be far more economical to electrically heat cars. Moreover, as we have seen, the electric heater gives off no deleterious gas to affect the ventilation of the car, and, owing to the ease with which the air required for the heating can be drawn from the outside of the car-body, renders an electrically heated car far more comfortable than a car heated by a coal or oil stove.

Space saved by use of electrically heated street cars.

The electric heater affords a very convenient method of heating the staterooms on board of passenger steamships or men-of-war, where electricity is employed for lighting and other purposes. Such heaters are placed far more readily in the staterooms than are the ordinary steam or hot-water heaters, since the former only require the running of the electric conductors, while the latter need the troublesome running of steam or hot-water pipes. But apart from the matter of convenience, the weakening of the framework of the vessel by the openings required for the passage of the steam or hot-water pipes, is an objectionable feature. Heaters for staterooms are constructed on the same general lines as for street cars. Generally, however, in the smaller staterooms but a single heater is required. A number of electric heaters for staterooms on a ship are

Electric heating of the staterooms of steamships.

shown in Fig. 238. Electric heaters are employed now on most all modern war vessels, since, on these vessels, electricity is employed for a very great variety of purposes.

Fig. 238.—Electric Heaters for Ships. This figure represents an equipment of state-room heaters for one of the Leyland Line ships.

There are many purposes for which electric heaters can be employed in the house. In the kitchen, for example, there are such devices as electric stoves, ovens, broilers, toasters, boilers, teakettles, coffee-pots, waffle-irons, griddle-cake cookers, plate-warmers, frying-kettles, etc. Electric heaters for cooking.

Fig. 239.—Electric Stove. Note the temperature-regulating switch placed near the bottom of the stove.

In the electric stove, as the word is now generally employed, the electric heater takes the form shown in Fig. 239. Here the heat coils are placed inside a short cylinder, the upper surface of which is flat, like Electric stoves.

the top plate of an ordinary cook stove. The articles to be heated are placed on the top of the stove plate. In order to ensure the best results, it is necessary that the vessels in which the heating, cooking, etc., are to be carried on, be provided with a flat base, so as to come in direct contact with the surface of the stove plate. For this purpose, it is far more economical to employ only vessels especially made for such uses. These vessels, too, are generally provided with some form of attachment to the stove plate. It has been found advisable to make the diameter of the vessel somewhat larger than that of the plate of the stove on which the vessel is to rest. Vessels with copper bottoms are preferable to vessels of enamel, the operation of cooking being much more rapidly carried on in the former than in the latter case. This has been found especially to be the case where there is a quantity of water or other liquid to be boiled. In a suitably designed vessel, this can be accomplished in a few minutes, while in an imperfectly designed vessel it may require either a longer time, or it may be impossible to attain the boiling point no matter how long the heating is continued.

Care necessary in construction and use of vessels for use in electric cooking.

Electric stoves are generally provided with a heat regulating switch, so arranged as to readily give a number of different temperatures. Such a switch results in a great saving of the amount of electric current required for any given operation. Generally, the full heating current should be turned on at the beginning of the operation, and when partly or nearly completed, the switch can be turned down, so as to cause a small amount of current to pass through the heating coils. For example, after a quantity of water has been brought to the boiling point by the full current strength of the heater, a much smaller

Use of regulating switch in electric cooking apparatus.

current will suffice to continue the boiling. But the regulating switch not only ensures economy of current, but it also renders the cooking much more satisfactory. Generally, the electric stove will acquire its full temperature in from three to five minutes. After this, a smaller current will suffice to keep it hot. Where it is only desired to keep food, that has already been cooked, warm and ready for the table, either a small current can be obtained by the switch, or the current can be entirely cut off, provided, in the last case, the food is not required to be kept hot for a longer time than from fifteen to twenty minutes.

In the electric oven, as in the ordinary oven, a hot air space is provided for baking and for all the operations that are generally carried on in an ordinary oven. In such case, the use of the regulating switch affords a great convenience, in order to ensure that temperature which experience shows is best suited for different kinds of work.

Electric ovens.

In order to know the exact temperature existing inside an electric oven, some form of mercurial or metallic thermometer is generally provided. In the particular oven here shown, a form of metallic thermometer or pyrometer is placed in the middle of the oven door. In order to retain the heat, the walls of this oven are tripled, and are filled with powdered asbestos or some other non-conducting heat medium. In the electric oven, represented in Fig. 240, the pyrometer is shown at the middle of the door, and three regulating switches below the door. In any of the ordinary operations that are carried on in ovens, the results obtained in the quality of the cooking depend greatly on the uniformity of temperature, on the ability of obtaining desired

Use of thermometer or pyrometer in electric ovens.

changes of temperature at will, and especially on the freedom of the oven from draughts of air while the cooking is being carried on. The electric oven ensures all these requirements far better than any other form of oven in general use. Moreover, the electric oven possesses the advantage over such ovens as are heated by gas or by oil, from the absence of any deleterious gases liberated as products of combustion or from partly consumed gas.

FIG. 240.—Electric Oven. Note the pyrometer at the centre of the oven door. Note also the temperature-regulating switches below the door.

Advantages of the electric broiler.

In the electric broiler represented in Fig. 241, the operation of broiling a steak or a fish can be carried on much more satisfactorily than with an ordinary broiler, owing to the fact that the food to be broiled is not exposed to the gases that are given off from glowing coals. Moreover, none of the juices of the meat need be lost, since, as represented in the figure, the fluted broiling surface is slightly inclined, so that the juices run off and collect in the cavity represented at the left-hand side of the figure.

It is in such operations as broiling, where a high temperature is required, and which, in the case of hotels and restaurants, may be called for at any moment, that the advantages of the electric over ordinary broiling by a coal fire are manifest. Instead

FIG. 241.—Electric Broiler. Note the grooved channels provided to catch the juices of the meat.

of constantly maintaining a glowing coal fire during many hours of the day, the electric broiler can acquire its maximum temperature in a very few minutes, and, therefore, need not be kept in operation until the order is received. Moreover, instead of being obliged to maintain a single large broiler, where electric broilers are employed a number of smaller ones may be used.

FIG. 242.—Electric Griddle-cake Cooker and Toaster.

Electric toaster and griddle-cake baker.

In the electric griddle-cake cookers and toasters shown in Fig. 242, the arrangement is very similar to that of the electric oven. The advantage of electric heating over the ordinary methods in these lines of cooking lies in the greater cleanliness, and in the ability to ensure a constant temperature. In the

electric waffle-irons shown in Fig. 243, besides the advantages above named, there is found the additional advantage that both the upper and the lower surfaces of the irons can be heated at the same time. Consequently, the irons do not require to be turned, and a more uniform baking is thereby ensured.

FIG. 243.—Electric Waffle-irons.

In an electric coffeepot or biggin, an electric stove is provided with a permanently attached pot, as shown in Fig. 244. A similar arrangement is adopted in the electric chafing-dish shown in Fig. 245. Regulating switches are provided in each of these devices.

FIG. 244.—An Electric Coffeepot or Biggin.

Electric kitchen equipment.

There are a number of other devices suitable for electric cooking that are operated on the same principles as those above described. A further description, however, of this type of apparatus is unnecessary. There is represented in Fig. 246 a general electric kitchen equipment, in which different electric

devices are shown. Here a switchboard, provided with a knife switch for opening and closing the circuit, is seen, with wires running to the different

Fig. 245.—An Electric Chafing-dish.

apparatus. Plug switches are provided for the ready attachment of the different electric devices. The different apparatus shown in this equipment will be readily recognized.

Fig. 246.—An Electric Kitchen Equipment. The apparatus shown in this figure is capable of cooking for some thirty people.

Electric tube or coil heaters.

When it is desired to raise the temperature of a fairly large quantity of water to the boiling point, it may be done in a suitably shaped vessel, placed on the surface of the ordinary electric stove. A far

more convenient manner, however, for some purposes, is by the use of an electric immersion coil. These consist, as shown in Fig. 247, of copper tubes, that are heated by electric heater coils placed within them. These tubes are immersed in the liquid that

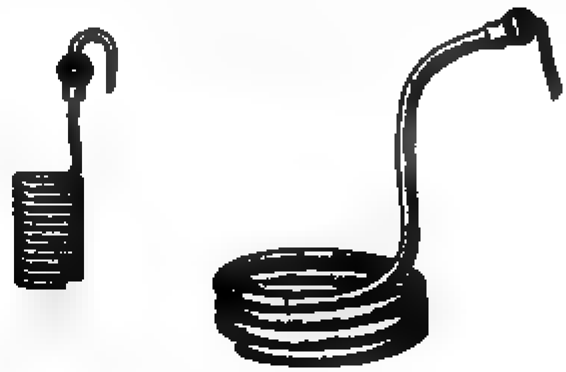


FIG. 247.—Electric Coil Heater for Heating Water and Other Liquids. The coil is immersed directly in the water to be heated.

is to be heated. Immersion heater coils are arranged either for a single temperature, or, by the use of the ordinary regulating switch, they may be arranged for a number of different temperatures.

Electric smoothing or flat iron.

The electric smoothing or flat iron is a form of an electric heater that is capable of doing very efficient and satisfactory work. The heating coils are

FIG. 248.—An Electric Smoothing-iron.

placed inside the iron case. The advantage in this form of apparatus consists in the fact that the proper temperature of the iron is maintained while the work is being done, so that the iron does not decrease in

temperature as the work goes on, which is the case with the ordinary form of smoothing or flat iron. A form of electric smoothing-iron is shown in Fig. 248. Where ironing is done by machinery, as in laundries, by heated rolls, electric heaters can be

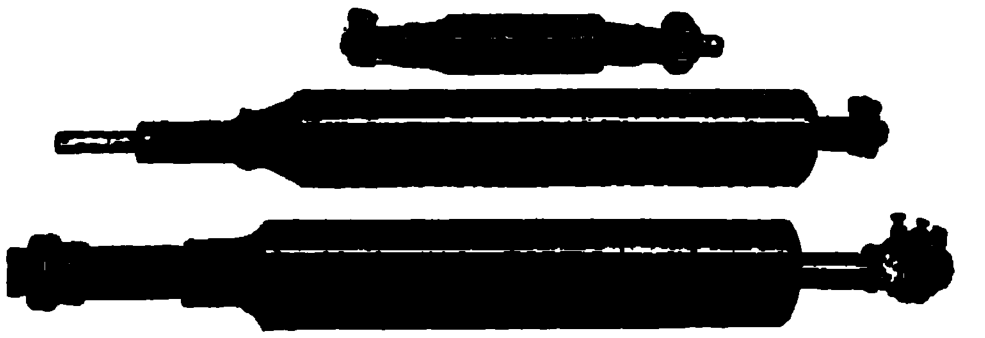


FIG. 249.—Electrically Heated Rolls. The rolls are driven by machinery.

readily placed inside these rolls, so that the heat can be conveniently applied to them. Some forms of electrically heated rolls are shown in Fig. 249.

By placing electric heating coils near the copper end of an ordinary soldering-iron, there is produced an electric heating iron that acts very satisfactorily. An electric soldering-iron is shown in Fig. 250. **Electric soldering-iron.**

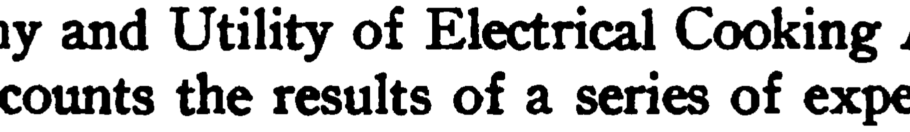


FIG. 250.—An Electrically Heated Soldering-Iron.

Prof. J. P. Jackson, in a paper read before the American Institute of Electrical Engineers on "The Economy and Utility of Electrical Cooking Apparatus," recounts the results of a series of experiments that he made on the economy and practicability of various forms of electric heating devices. He gives the result of these tests as follows: **Jackson on tests in electric cooking.**

"The results of the cooking tests seem to indicate that for the usual cooking of a family for the whole year, the expense would be larger than would be ordinarily acceptable, notwithstanding the great advantages in other respects. However, in the follow-

ing classes the utility of electrical cooking utensils should be great:

"1. For light housekeeping, such as is practiced in small city apartments, and in many larger houses during the summer months, no other method presents so many desirable features. The dirt of coal and ashes, disagreeable gases and abnormal temperture due to a coal stove, are entirely avoided. For such housekeeping, a disk stove using 500 or 600 watts and a broiler using about 1,200 watts would be sufficient for a small family, and would cost from $20 to $30. A teakettle or immersion coil might be added, at a cost of from $6 to $10. A special pair of wires would of necessity have to be run into the cooking-room from the house or apartment supply mains. The latter would ordinarily warrant the extra call that would be made upon them in this way. For similar purposes, coal-oil, gas, or gasoline are frequently used, but with the inherent disadvantages of greater heat in the room, offensive odors, comparative uncleanliness, and danger.

Ready installation of electric cooking apparatus in electrically lighted house.

"2. This form of cooking apparatus could be used with facility in boarding-houses and restaurants for purposes which require an even temperature, such as is needed in baking griddle-cakes, boiling eggs, etc.

"3. Where electricity is available, nothing could be more convenient than a small electrical stove, requiring 300 or 400 watts, for the many uses to which at present the alcohol flame is put, such as the afternoon teakettle, chafing-dish, toaster, etc. This use of alcohol is most unsafe as regards danger from fire, and could well be discarded for electricity, which is absolutely safe when properly installed, as well as being more convenient and better in other respects.

"4. In the shop, the glue-pot, solder-pot, brazing-iron, etc., can be heated advantageously by electricity, and one of the most gratifying consequences of

our experiments has been the decision to put such an equipment in our college shops.

"5. The test of the electrical flatirons showed them more economical than the old form, when the saving of labor is taken into account. Not only is there a saving in time, but the severity of labor is much lessened. Our experience is that a laundress who has used an electrical iron would be exceedingly unwilling to go back to the old form.

"A small flatiron of two or three ampères attached to the ordinary lighting fixture in a dressing-room is a great convenience; and with the electric tea-kettle and curling-iron is destined to become essential in the modern home.

"Concerning the question whether the use of electricity had proved satisfactory in its operations in the cooking tests described, the housekeeper in charge said: 'The instruments were excellent in every respect. We were able to cook more rapidly, to keep the heat at just the right point, and could readily prevent over-cooking or under-cooking. While we were using electricity every dish was perfect. When I think of these advantages and of the cleanliness and convenience of the utensils, I sincerely hope that some of them at least may be retained in the house permanently.'

Great variety of applications of electric heating apparatus.

"The general results of the tests were of such a nature that the writer is warranted in the belief that if central station managers would more generally introduce exhibition equipments of these domestic utensils, a new call on their station capacity would develop, of which the larger proportion would be during the light load periods."

Electric heating has been successfully applied to the baking of crackers on a commercial scale at Niagara Falls, where a cheap electric current can be

The electric baking of crackers on commercial scale at Niagara Falls.

obtained. As in the ordinary process of baking crackers, here the pans are placed in a horizontal position on the circumference of a revolving cylinder, the pans being so hung that, during the rotation of the cylinder, they remain suspended in a horizontal position, as in the case of the seats in the well-known Ferris wheel. The temperature of the oven is so regulated, as regards the time required for a complete revolution of the cylinder, that the crackers are baked during a single revolution of the wheel. The pans are therefore ready to be removed and replaced by fresh pans of unbaked crackers as soon as the cylinder in its revolution brings the pans back again to the door at which they were placed on the rotating cylinder.

Mr. T. C. Martin, in a report prepared for the United Census Bulletin for the year 1902, thus refers to the application of electric heating on a comparatively large scale for industrial purposes at Orange, N. J.:

Martin on the application of electric heat in a hat-felting factory at Orange, N. J.

"One of the most striking illustrations of the application of electric heat to industrial purposes is that afforded by a hat factory at Orange Valley, N. J., where no less than 250 horse-power of electrical energy is used for heating purposes. In a hat factory two kinds of heat, broadly speaking, are usually required, that of low degree, for sizing and coloring vats, etc., and that of high degree, for the hat-finishing tools. In the factory referred to, the latter form of heat is all supplied by electricity, while the exhaust steam from the electrical generating plant is utilized for all the various other purposes not requiring a higher temperature than can thus be obtained. With regard to felt hats, it may be noted that the shaping process consists in placing the very rough shape on one or more blocks, and

then bringing it to the desired finishing shape by means of heat applied by irons. The different parts of the hat are not of equal thickness, the brim being the heavier and the crown the lighter portion, so that different degrees of heat are required when finishing different portions of the hat. Electric irons lend themselves with peculiar adaptability to such work, as different degrees of heat can be supplied at will, and any temperature can be definitely maintained at the proper point. Formerly, the heat for machine irons was supplied by gas-jets, and constant attention was necessary to ensure that the temperature did not become too high or too low.

"Under the old method, in each of the several hand-finishing rooms, where about 125 men were employed, and hot slugs were used, it was necessary to replace at short intervals those slugs that had become cooled with others taken red-hot from the furnace. To heat these slugs there were three furnaces on a floor, consuming three tons of coal per day, and in summer time causing an unbearable heat. Moreover, the frequent journeys of the men from their tables to the slug furnaces reduced their productive capacity, while the stream of men going to-and-fro congested the passages and disturbed the others at work. At the present time, it is not necessary for any man to move from his particular part of the bench, and all he has to do to keep his electric slugs at the right temperature is to throw in and out a little switch placed on the wall within easy reach. These same advantages appear in connection with the electric curling machines and the flanging pads employed to define and finish the brims. As to the economy of electric heat in this particular application, it is stated that where formerly eight tons of coal were used per day, now with one-third greater capacity only ten tons have been

Advantages found in practice to be derived from the electric finishing of felted hats.

used; moreover, the gas bill was formerly $200 per month, while fuel and attendance for the slug furnaces amounted to $10 per day. This, moreover, does not entirely represent the economy derived from the use of electrical apparatus, as the percentage of hats injured in the process of finishing is less, on account of the use of electric heat. The workmen, moreover, enjoy greater comfort and better health."

The incandescent electric lamp as an efficient electric heater.

An incandescent lamp can be employed for an efficient electric heater. Since only from two to three per cent of the energy of the current is converted into light, and the balance into heat, it will be seen that the ordinary incandescent lamp must form a very efficient device for converting electric energy into heat energy. The employment of electric incandescent lamps for heaters is, therefore, quite common. For example, we have already referred to the use of such an incandescent electric lamp in connection with the thermostat used by Mr. Edison in his electro-chemical meter. Here the arrangement is such that a fall of temperature produces a warping or bending of the thermostat bar, formed of brass and steel, so as to cause it to close the contact of an incandescent electric lamp. When the temperature of the confined space passes beyond a certain limit, the movement of this bar in the opposite direction breaks the contact, and thus throws the lamp out of the circuit.

Use of electric lamps as heaters of incubators.

Incandescent electric lamps have also been employed for electrically heating incubators, the compound bar of brass and steel employed as a thermostat introducing an incandescent lamp into or removing it from the circuit as the temperature falls below or rises above a certain predetermined limit.

Incandescent electric lamps have also been employed in a variety of electric cooking apparatus with fairly satisfactory results. Some forms of electric heaters, that depend for their operation on the heat produced by an incandescent electric lamp, are shown in Fig. 251. When such lamps are employed to heat metallic vessels, it is necessary to blacken the inside of the vessels, so as to render the metal a good absorber of heat. Otherwise, much of the heat would be lost by reflection. It has been found that, by the use of a 50 candle-power incandescent electric lamp em-

Electric incandescent lamp heaters.

FIG. 251.—Electric Incandescent Lamp Heater.

ploying 200 watts of activity, 2½ pounds of water can be brought to the temperature of the boiling point in somewhat less than half an hour.

The practical applications of electricity to cooking have been carried to such an extent that it is now quite a common occurrence to have the cooking for a considerable number of people done by electric means. Electric appliances for these purposes are employed in some of the galleys of men-of-war; and in some large manufacturing establishments, such, for example, as that of the General Electric Company at Schenectady, New York, large restaurants prepare their cooked food entirely by electric means. In some parts of the country, as, for example, at Utica, New York, apartment houses have been constructed with complete electric kitchen equip-

Electric cooking as carried on in restaurant at General Electric Company's shops at Schenectady, N. Y.

ments. All these installations have given considerable satisfaction.

Electric furnaces.

The heat developed by the carbon arc light is also capable of being employed for artificial heating. For all purposes of cooking, however, the temperature is far too high for practical purposes. All electric furnaces, however, which are, to a certain extent, a variety of chemical cooking apparatus, depend for their operation on the heat developed either by the direct arc or intense incandescence.

CHAPTER XXX

ELECTRIC WELDING

"Thomson's welding process consists in passing an electric current of great volume, by means of two clamps of good conducting metal (generally copper), through two pieces firmly abutted against each other between the clamps, which, when heated by the current, are forced together by mechanical pressure. The metal between the clamps alone possesses the requisites for the conversion of electrical energy into heat. The only loss of energy to be counted on will be that caused by conduction of heat to the clamps of the apparatus, by radiation, and the resistance loss in the electric generator and welding machine. By increasing the speed of operation the first two items, which are alone of importance, will be reduced."—*Electric Welding and Metal-Working*: HERMAN LEMPE

IT has been known for a long time that, when the surfaces of two masses of metal are brought to the temperature at which the metal begins to soften, and are firmly pressed together, they cohere, **Welding.** and become welded into a single piece. If the welding process has been properly carried on, the point of welding union can scarcely be detected, while the cohesion of the two metals is as good at the welded point as at any other point on their mass. There are some metals, notably lead, that possess the power of being welded while at ordinary temperatures. If two clean, bright surfaces of lead be firmly pressed together, they will cohere strongly.

The following simple experiment illustrates the property of lead to be welded while in a cold state: **Welding at ordinary temperatures.** Cast a cylinder of lead about two inches in length and one-quarter of an inch in diameter; then cut this cylinder into two equal parts by placing a sharp knife against its middle and striking it a few strong

blows with a hammer. Attach wires to the two pieces, as shown in Fig. 252. If, now, while the two surfaces of lead are clean and bright, they be pressed firmly together, they will be found to cohere so strongly as to be able to support a comparatively heavy weight placed on a scale pan formed by tying strings to the four corners of a piece of stout pasteboard, as shown.

FIG. 252.—Welding of Lead at Ordinary Temperatures. Care should be taken not to touch the freshly cut surfaces of the lead with the fingers, since the thin coating of grease so obtained will greatly lessen the strength of the cohesion.

Long experience necessary to obtain good welded joint by ordinary process.

In order to ensure a good welded joint, the surfaces of the two metals must be kept clean and free from oxide, which is rapidly formed when the metals are heated in air to temperatures near their points of incandescence. This freedom from oxide is easily obtained by the use of some suitable flux, such as borax, which removes the film of oxide on the metallic surfaces by entering into combination with it. Considerable skill is necessary in order to obtain a good welded joint. One of the most important considerations is the temperature, which varies with the different metals. In welding by the ordinary processes, the workman determines when the re-

quired temperature is reached by the color and other general appearances of the metals while they are heating. He learns by a costly experience just what these appearances are. In electric welding by incandescence, as soon as experience has shown the proper temperature which is required to obtain the best results, this temperature can invariably be rapidly produced by subjecting the mass of metal to the particular current strength required.

There are two different systems of electric welding; viz., that invented by Prof. Elihu Thomson, and generally known as the incandescent-welding system, and that of Bernardos, and generally known as the arc-welding system. The former is by far the best system for most characters of work, and has, indeed, reached so extended a condition that it may now properly be regarded as one of the electric arts. The Bernardos system, in point of fact, would more properly be styled a system of electric soldering. We will discuss the Bernardos system first, as of less importance than the other.

The Thomson and the Bernardos systems of electric welding.

In the electric furnace devised by C. William Siemens, to which we have referred in the preceding pages, there was employed for the rapid melting or fusing of metals a crucible of hard conducting carbon. The metal to be fused was placed inside this crucible, which was connected with one of the poles of a powerful continuous-current dynamo. The other pole was connected to a central rod or cylinder of hard carbon, so supported that it could be readily moved toward and from the charge contained in the crucible. The metal to be fused being placed in the bottom of the crucible, the movable carbon electrode was brought in contact with it, and then slowly raised. By this means, an arc was

Siemens's electric metal-melting furnace.

formed directly between the electrode and the mass of metal in the crucible. Under these circumstances, the fusion rapidly took place.

In the Bernardos welding process the electric arc is formed between the pieces of metal that are to be welded together. This process is capable of two distinct applications; viz., for the purpose of filling blow-holes in iron castings, and for the purpose of welding or soldering two metals together. In the first process the castings are first heated in an ordinary furnace, and are then connected with the positive pole of a continuous-current dynamo, while a piece of metal of the same character as that of the casting is connected with the negative pole, and is brought into contact with the blow-hole that requires to be filled. On the separation of this, a short distance from the metal an arc is formed and the fused metal falls into the cavity, filling it. At the same time, the adjoining portions of the metal are softened or partially fused, so that, under these circumstances, the added metal becomes thoroughly incorporated with the surrounding metal, thus forming one continuous, uniform, homogeneous mass. The process is generally referred to as resulting in the welding together of the two masses of metal. The previous heating of the casting is necessary in order to avoid cracking from the shrinkage of the mass. The application of the Bernardos process is especially applicable to the longitudinal welding of riveted plates. In thin plates, the arc alone is sufficient.

The electric filling of blow-holes in metallic castings.

Bernardos system for welding or soldering longitudinal joints.

In the welding or soldering of larger plates by the Bernardos system, however, some form of electric blow-pipe is necessary. A form of apparatus devised by Werderman, and originally employed by

him as an electric blow-pipe for the purpose of boring holes in rocks for receiving blasting charges, consisted in the combination of a voltaic arc and an electro-magnet, so as to deflect the arc in the well-known manner. This deflection causes the arc to act as a blow-pipe, the flame being directed against the surfaces that are to be welded together.

Electric blow-pipe for arc soldering or welding.

A curious process, whereby the electric heating of metals for welding or forging is readily obtained, consists in placing the metal to be heated in an aqueous solution of some salt, such as soda, which increases the conducting power of the water. This solution is placed in a vessel lined with plates of lead. The conducting lining of the vessel is connected with the positive terminal of a continuous-current dynamo, while the metal to be heated is connected with the negative terminal of the same source. On plunging the metal below the surface of the saline solution, electrolysis takes place, and the liberated hydrogen appears as a film of gas on the surface of the negative electrode, that is, on the surface of the metal that is to be electrically heated. On account of the electric resistance of this film of hydrogen, an exceedingly high temperature is produced on the surface of the metal, which, consequently, becomes rapidly heated throughout its entire mass. The surrounding envelope of hydrogen gas possesses the additional advantage of thoroughly protecting the surface of the metal to be heated from oxidation. This freedom from oxidation is, of course, an advantage whether the masses of heated metal are to be welded together, or whether they are to be forged by ordinary means. Another curious circumstance in this method, which adds to its convenience, is to be found in the fact that, since the principal resistance lies in the film of hydrogen

Welding or shaping of electrolytically heated metals.

at the surface of the metal which is to be heated, it is practically at these surfaces alone where the principal amount of heat is liberated. The value of the current, therefore, that passes can be made automatically to conform to the size of the piece that is to be welded, since, by varying the depth of immersion in the liquid bath, the resistance will decrease as the area of the immersed liquid increases, and thus will permit a greater current to flow in accordance with the needs of the particular case.

Prof. Elihu Thomson on electric welding.

Coming now to the Thomson system of incandescent welding, which is practically the only system that is in fairly extended use, we find that the invention was first suggested as early as 1877. Professor Thomson thus refers to this invention in a lecture delivered before the Franklin Institute in March, 1887:

Franklin Institute lecture of March, 1887.

"Ten years ago I had the pleasure of giving a course of five lectures on electricity in the Hall of the Franklin Institute, as part of the winter courses, and the leading idea I presented to my hearers was, that electricity, from whatever source, and however manifested, is always of the same nature, and differs from that produced in other ways in its tension or potential, which is analogous to pressure in fluids, and in volume or amount of current, which is analogous to rate of flow of fluid or to the quantity moving in a pipe or conduit past a given position in a definite time.

"Among the experimental demonstrations used to support this view, were some which were made with an ordinary induction coil, such as is commonly employed to obtain from low-potential battery currents high-potential discharges through air, resembling lightning, or what is often called static electric-

ity, such as is employed in the charging of Leyden jars, etc.

"After showing the induction coil as so used, I reversed the process and passed high-potential discharges from a charged battery of Leyden jars, through the fine wire coils of the induction coil, and received currents of low potential but of great volume from the coarse wire of the coil. By putting a low-resistance galvanometer in the circuit of the coarse wire, known ordinarily as the primary, a strong deflection of the index of the galvanometer took place, and upon bringing the ends of the coarse wire coil together in slight contact, a bright green flash took place at every Leyden-jar discharge through the fine wire. While repeating this instructive experiment, showing the identity of electricity and the reversibility of the induction coil, I noticed at one time that after the discharge the ends of the wire of the primary or coarse coil had stuck rather firmly together, and it then occurred to me that possibly metal wires might be united by properly organizing the appliances. My attention was turned, however, to the field of electric lighting, in the development of which field I have, since 1879, been almost exclusively engaged. Some four or five years ago the need of a quick and effective method of joining together the ends of copper and other wires, as in the construction of our dynamo machines and other electric apparatus, presented itself. The joints, as ordinarily made, were formed by tapering each end and soldering or brazing them together sidewise, and the joints were of clumsy and uncertain character, unless made with great care; and, moreover, destroyed the flexibility of the wire at the joint."

The inverted induction coil.

Electrically welded joints.

Electric heating by the Thomson incandescent

process can be effected either by continuous or by alternating electric currents. For most purposes alternating electric currents are preferable. As is well known, the amount of heat developed is the same whether the currents be continuous or alternating, provided, of course, the current strength remains the same. The reason that alternating currents are generally preferable for welding purposes is to be found in the fact that, in order to obtain the best results, the temperature reached by the welding substances should be the same throughout all parts of their surfaces. When continuous currents are employed, the loss of heat at the outer portions of the surfaces that are in contact with the air will naturally result in the central portions remaining at a higher temperature. For this reason, it is more difficult to obtain good welded joints over extended surfaces when the direct currents are employed. When, however, alternating currents are used, although the same chilling action takes place, yet the fact to which reference has already been made, that an alternating current tends to possess a greater current strength near the surface of a conductor than near its central parts, there is thus ensured a greater uniformity of temperature throughout the entire surfaces, and, consequently, a better welded joint is obtained.

Why alternating electric currents are preferable for electric welding.

As to the practical results obtained by the Thomson system of electric incandescent welding, it has been found, in actual practice, that far better welded joints can be obtained than with the ordinary method of welding by furnace heat. Moreover, metals can be welded electrically that can not be welded at all by ordinary methods, the electric process welding not only such metals as copper, steel, and iron, but also such metals as wrought-iron, zinc, gold, tin, aluminium, and cast-iron. Moreover, the character

Electrically heated *vs.* furnace heated welded joints.

of the welded joint is such that its tensile strength, instead of being weakened at the welded part, is quite as strong as it is elsewhere.

In the Thomson process of electric welding, where the ends of two pieces of wire, or of two bars of metal, are to be welded together, the ends are placed in contact for an ordinary butt or end-to-end joint. A direct or alternating current is then passed between them across the contact surfaces. The high resistance that exists at the contact surfaces causes the heat to be generated in a greater proportion at this point. As soon as the ends have acquired the welding temperature, they are pressed firmly together. Sometimes, a flux, such as borax, is employed, in order to keep the surfaces to be welded free from oxide, as in the ordinary process of welding.

The Thomson process.

In order to be able to control the temperature at the welding surfaces, suitable devices are used for the purpose of controlling the current strength. It is by reason of the ability to thus prevent the temperature from passing beyond a certain limiting temperature, that it has been possible to successfully weld certain varieties of steel, that can not be heated beyond a certain temperature without being injured. For the same reason, such readily fusible metals as lead, zinc, and tin may be welded, provided a suitable flux, such as resin or zinc chloride, is employed instead of borax.

Necessity for current-controlling devices in electric welding.

There are two distinct forms of apparatus employed in the Thomson system of incandescent electric welding; viz., direct welders, in which the alternating current is employed directly as it is produced by the dynamo, and indirect welders, in which the

Direct-welding apparatus.

alternating current is passed through transformers that are suitably designed for the purpose of producing the current and pressure required. An apparatus belonging to the type of direct welders is shown in Fig. 253. Here the alternating currents,

FIG. 253.—Thomson Direct-welding Apparatus for Welding Iron Hoops.

produced by a suitable alternator, are employed directly, without the intervention of a transformer. Such apparatus is suitable for small work only. This apparatus is intended for the welding of iron hoops, one being placed in the clamps in the upper part of the apparatus, to be welded. An alternating dynamo, driven by the pulley P, produces the necessary current. A rheostat, R, placed at the lower left-hand side of the figure, is employed for the purpose of controlling the strength of the cur-

rent from the commutator to the field coils of the machine.

Wherever large work is to be welded, the indirect welder is employed. The transformers are built in the usual manner, and are of the step-down type. In cases of very large work, which is too heavy to be taken to the transformer, the latter is so constructed that it can be readily taken to the work. A form of such transformer is represented

Indirect welder for large work.

FIG. 254.—Indirect Welding Transformer for Heavy Work. Here the step-down transformer lowers the pressure, but greatly increases the current strength.

in Fig. 254. The primary coil is placed in a rectangular frame. The secondary consists of the outer shell of the transformer, formed of copper castings, that are firmly bolted together. Oil is placed inside the transformer for the purpose of insulating the two coils and carrying off the heat generated.

Since no little skill is required in order to apply the proper degree of pressure to the surfaces that are to be welded, the plan is generally adopted, as soon as the welding temperature has been attained,

of applying this pressure automatically. Welding apparatus of this type are called automatic apparatus, in order to distinguish them from hand apparatus in which the pressure is applied manually. In

Automatic electric welding apparatus.

automatic welding apparatus, the amount of pressure required may be obtained either by means of weights, or in any other suitable manner. A form of automatic welder is shown in Fig. 255. In this case, the pressure is obtained by means of weights, W, suspended as shown. The transformer, T, is

Fig. 255.—Automatic Welding Apparatus. Here the exact pressure required to ensure the best welded joints is obtained by the regulable weight W.

seen in the middle part of the figure. The weights cause the work that is to be welded to be pressed together in the clamps K, K. The movement of these clamps at the proper moment makes the contact which operates the electro-magnet EM, and this latter, by the attraction of its armature, thus cuts off the welding current as soon as the operation is completed.

The process of electric welding has been applied

practically to a great variety of purposes. In the shrapnel shell, a hard steel point is welded to the soft steel body of the shell. This very difficult type of welding can be readily accomplished by means of the electric apparatus represented in Fig. 256, which shows a device especially suited for this purpose.

Electrically welded shrapnel shell.

One of the most remarkable applications of electric welding is that employed for the purpose of obtaining a good electric contact between the ends of the

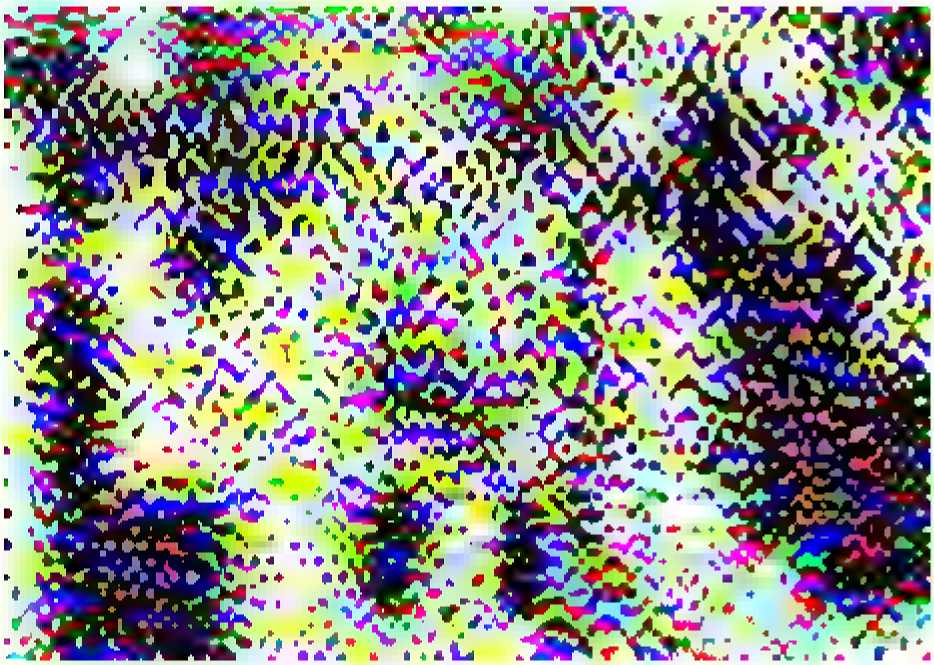


FIG. 256.—Thomson Apparatus for Welding Shrapnel Shells.

rails of street-car tracks. We have already referred to the difficulty of employing the tracks for the return circuit by reason of the high resistance at the joints between contiguous rails, and have described various forms of bonds for such purposes. By the use of suitable welding apparatus, the ends of two rails can be welded together so as practically to form one continuous rail. In a track so welded, there is no greater resistance at the welded joint than there is at any other portions of the track. The electric power required for this welding is generally drawn

directly from the trolley wire, the continuous current so obtained being employed to drive a rotary transformer. In this manner, the continuous current em-

FIG. 257.—Thomson Welder for Welding Rails on Street Railway.

Electrically welded car tracks.

ployed by the street-car system is converted into alternating currents. A form of electric welder employed for welding car tracks is shown in Fig.

FIG. 258.—Electrically Welded Car Rails. Note the heavy character of this kind of welded work.

257, actually engaged in welding together two ends of a track on a street railway. Here the welding transformer is represented at T T. The heavy jaws,

J J, pivoted at V V, are kept apart by means of suitable springs, Z′ Z′, but can be forced together by the action of a hydraulic pump, P, so as to exert a transverse pressure through the secondary terminals, Z Z. The general appearance of two rails after they have been welded together is shown in Fig. 258.

Electric welding has been practically applied to quite a variety of purposes, but our space will pre-

FIG. 259.—Thomson Metal Wheel Spoke-welding Machine.

vent any further description of this interesting art. Mention, however, might be made of the form of apparatus shown in Fig. 259, which is especially designed for welding the metal wheel spokes to the hub of the wheel.

Thomson spoke-welding machine.

As to some of the results that have been obtained by the Thomson system of electric welding, the following may be quoted from the lecture by Pro-

fessor Thomson to the Franklin Institute, before referred to:

"The results obtained in the application of electric welding to the various metals, promise to be of great practical importance. While ordinarily it has been the exception that metals weld readily, with the electric method no metal or alloy yet tried has failed to unite with pieces of the same metal, and the trials have included most of the metals commonly known —such as wrought-iron, mild steel, tool steel; special steels, such as Mushet steel; and even cast-iron joints have been made between these different varieties of iron. Copper and its alloys, brass, bronze, German silver, etc.; silver, pure and unalloyed, gold, likewise platinum, zinc, tin, lead, aluminium. The list is being extended as time and facilities permit.

Some results obtained by the Thomson electric welding system.

"Joints between different metals or alloys are often easily produced if their physical properties are not too unlike. Copper, brass, German silver, steel, and iron can be united one to the other, and in some cases the joints are of remarkable firmness and strength. I will close the present paper with a list of possible extended applications of the process in the arts, which is, of course, subject to extension in the future.

Character of electrically welded joints.

"(1.) Joining wires, or bars, end to end, whether round, flat, square, or polygonal in form. Under this heading would come making of long lengths of wire for telegraph and telephone line work, and joining small sections of wire into one length as in the construction of electrical apparatus. The specimens exhibited show varieties of such work.

"Very large bars of iron or steel may, it is believed, be welded when the power of the apparatus is proportionately increased. The operation is undoubtedly economical of heat, because the heat used, whether obtained from steam or water power in-

directly, is concentrated just where it is needed for the work and is perfectly regulable. With large pieces, a saving of loss of heat by radiation and convection to the air may be effected by applying a covering or shield lined with a non-conductor of heat, and made in sections to fit over and inclose the work, and either resting on it or kept out of contact, as the case may be.

Concentration of electrically developed heat reduces extra cost of electric welding.

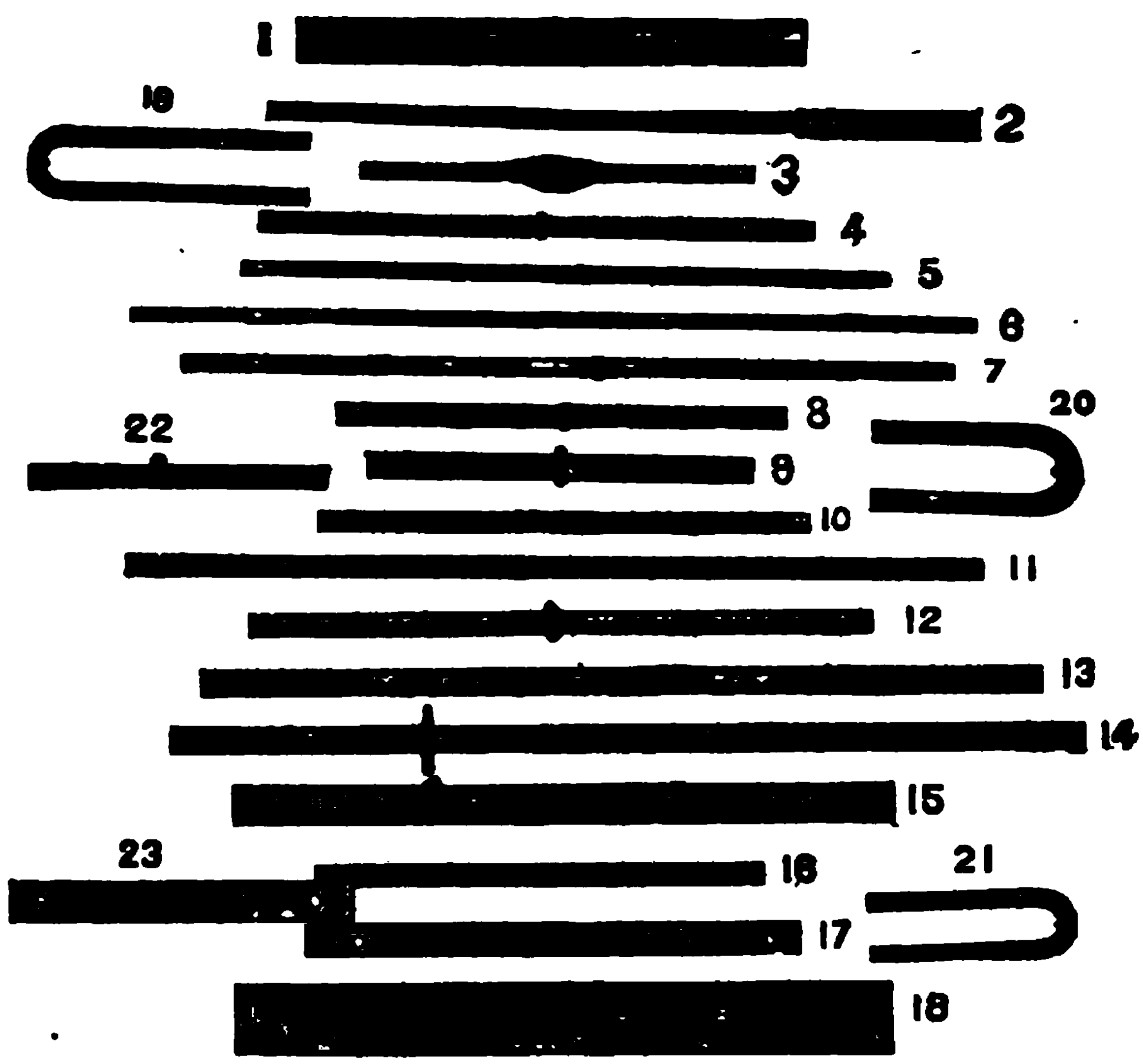


FIG. 260.—Some Specimens of End-to-End Electrically Welded Joints.

"Examples of the welding of bars end to end appear in Fig. 7 [our Fig. 260], which is taken from a photograph of bars of iron, steel, copper, brass, zinc, lead, etc. Some of the bars, 19, 20, and 21, have been bent after welding. Bar 2 is composed of iron, copper, and brass. Bar 3 is of copper, but has been hammered out flat at the weld. Bars 16, 17, 18, and 23 are square or rectangular in section. Bar 15 is composed of two pieces of cast-iron welded

Some specimens of electrically welded bars.

together, and the resulting bar in turn welded to a wrought-iron piece.

Specimens of electrically welded tubular joints.

"(2.) Tubes and hollow forms of various metals may be welded together with facility, and it would be quite within the bounds of easy practicability to lay welded lines of wrought-iron or mild steel, or even cast-iron pipe, with few or no screw joints. A

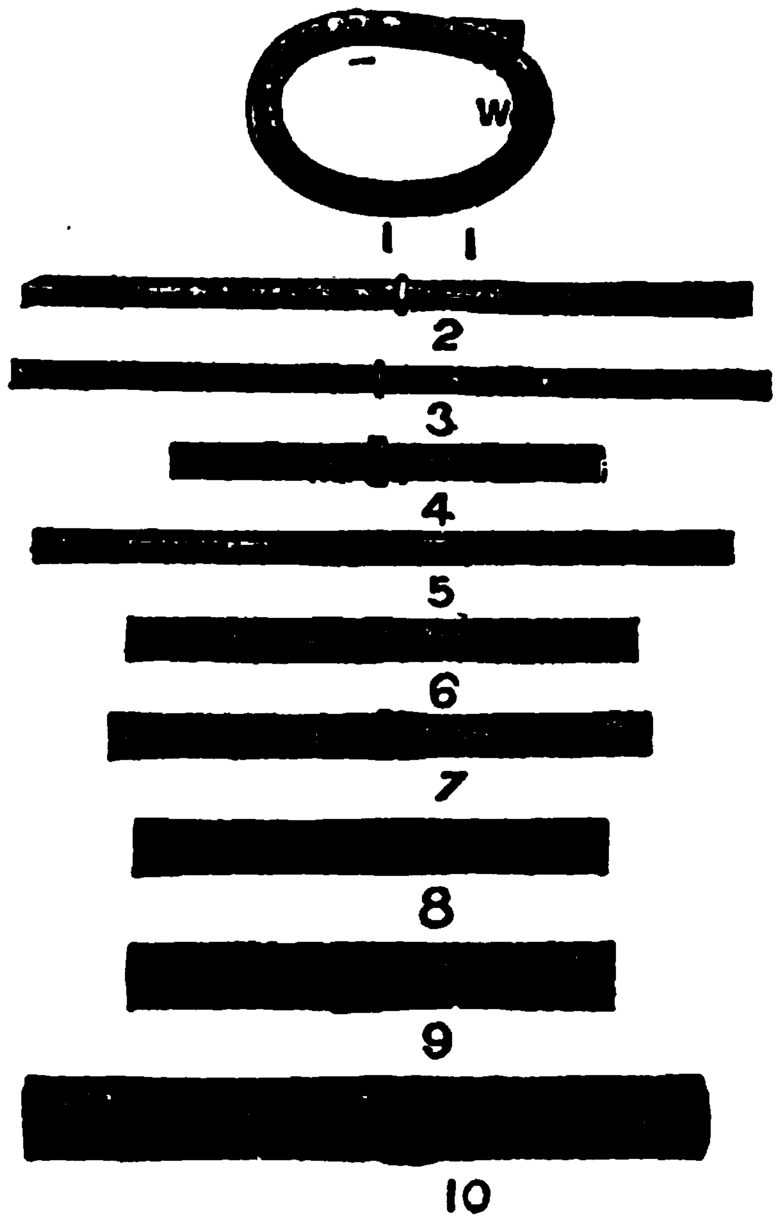


FIG. 261.—Some Specimens of Electrically Welded Tubes.

small wire may convey the current to the place where the work is to be done, and the induction apparatus may be mounted so as to be portable. As the joining of lead pipes is effected with ease, a soldered or wiped joint need no longer tax a plumber's skill. With wrought-iron pipe, the joints can be pressed or hammered, while the heat is maintained by the current. The specimens here shown give some idea of the work accomplished Fig. 8 [our Fig. 261] rep-

resents the appearance presented by tubes of lead, brass, copper, and iron in which a butt weld exists. Some of the joints have been hammered during the welding. No. 1 is a lead pipe, bent at W, after welding.

"(3.) Endless hoops or rings, such as wheel, ties, barrel, and tank hoops, band saws, chain links and chain, endless wire cables, etc., may be easily made or mended. Some examples of such work are here shown; one of the most notable of which is a piece of chain, all the links of which have a double electric weld; or, in other words, the links are made of two U-shaped pieces welded together at both ends simultaneously. One of the links is made of such pieces with a central cross-bar inserted and all welded together, the said bar dividing the link at its centre.

Electric welding of endless joints.

"(4.) Making and repairing steel and iron, or other metal articles, such as screw bolts, taps, drills, knives, and cutting instruments. There is an endless variety of this work, which can be materially assisted or simplified by electric welding. Bolts are lengthened or shortened as desired; taps, drills, augers, bits, reamers, etc., are in like manner lengthened. Poorer steel may be used for the body of a tool, and better for the portion which forms the cutting edge. Lathe tools, worn or shortened by use, may be pieced out with facility. Different diameters of steel bar can be united readily, so as to save forging and save material. Very delicate work, as in jewelry, may be effected. The construction and repair of delicate tools and appliances can be facilitated in many cases." Some specimens of such work are shown in Fig. 262.

Welded screw bolts, taps, drills, etc.

In addition to the above described processes of electric welding, there are several other processes de-

pending on the electric heating of metals. One of the most prominent of these is electric forging, or the working of various metals. In this process the metal to be forged is subjected to the passage of a powerful electric current, and as soon as the proper temperature has been obtained, it is then subjected to the action of a forge or hammer, as in the usual

Electric forging.

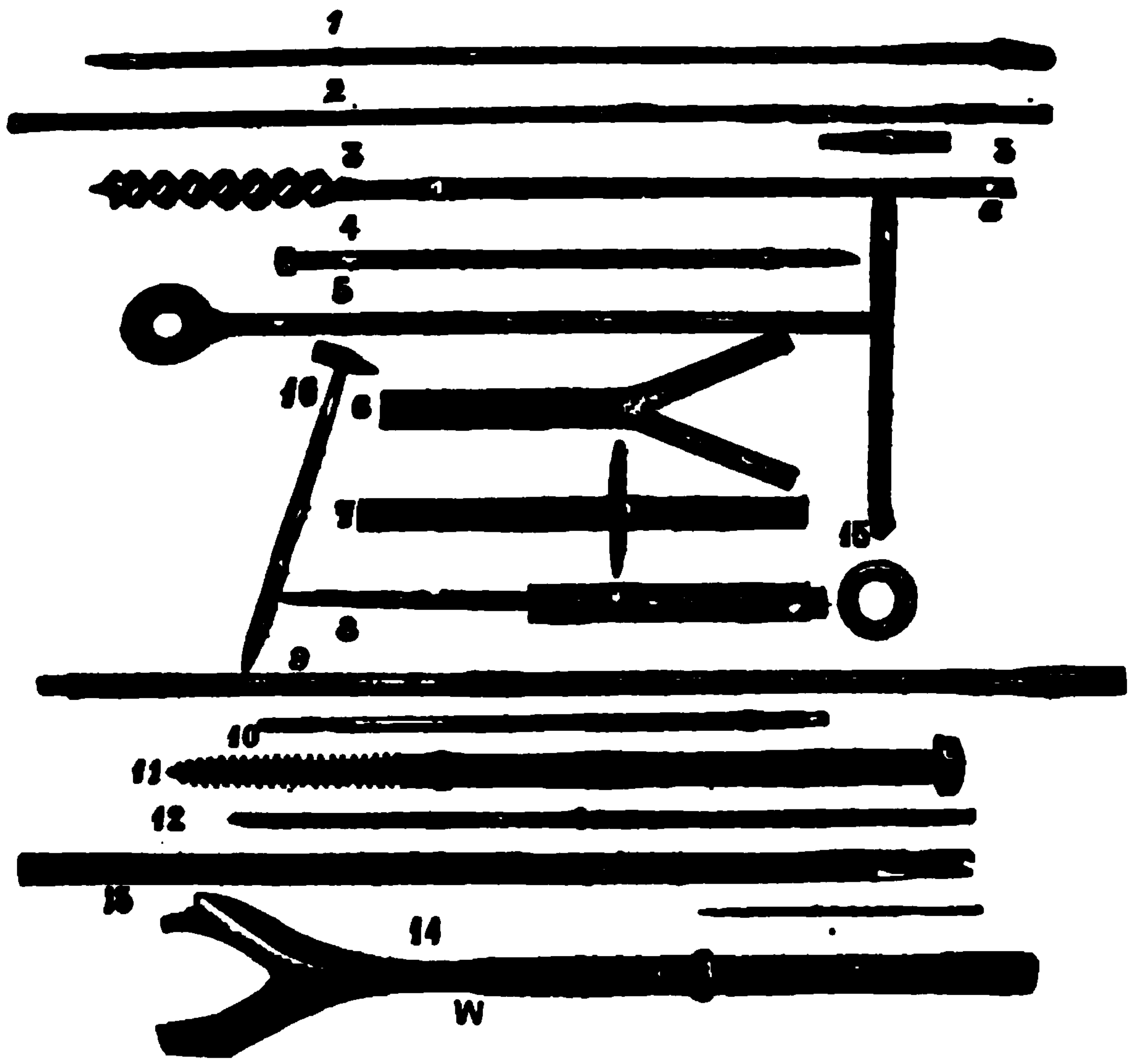


FIG. 262.—Specimens of Electrically Welded Taps, Drills, Augers, Bits, etc.

manner. For some purposes it has been found convenient to obtain the necessary increase in temperature by employing the path of conducting liquid already referred to, and then, at the moment when the metallic mass is suitable, it is removed from the path and placed on the forge and treated in the usual manner.

Another valuable application of electric heating is for electric annealing. In the process for producing what is called Harveyized armor plate, a low-

carbon steel plate is subjected to a process whereby the proportion of carbon it contains is increased. This change in the character of the steel affects the thickness of the plate from three-quarters of an inch to an inch. When such a plate is subsequently hardened by immersion in water, it becomes so exceedingly hard that it is able to resist the blow of a projectile better than any other armor plate that has been so far produced. At the same time, however, it is practically impossible to bore holes, such as might be required for the attachment of ladders, swivels, or other similar appliances, to the hull of the vessel. In order to be able to make these drill holes after the armor has been placed on the vessel, a powerful alternating current is sent through the mass of metal at the place where it is required to form the drill hole. If a voltaic arc were applied at this point, and the softened metal afterward allowed to cool, it would chill so rapidly, and again take on its hardness, that it would still be impossible to drill it by the ordinary method.

Process of electric annealing.

The method employed for electric annealing Harveyized plates consists in the following: Blocks of copper are placed on the surface of the plate where the holes are to be drilled. An alternating current is sent through the copper plates. As soon as a high temperature has been obtained, the current strength is gradually reduced, so that the cooling takes place slowly, and the plate consequently becomes sufficiently annealed to be acted on by the drill.

Electric casting of metal.

The electric heating of metals to the point of fusion has been successfully applied to the casting of metals. In this process, the crucible in which the metals are to be melted electrically is previously exhausted of air. The fused metal is then run into

the molds, which have also been deprived of their air. Under these circumstances, it is found that the fused metal flows much more readily, so that there is obtained a much more sharply marked casting than in casting by the ordinary method. Moreover, the texture of the cast metal is much finer grained, and the entire casting free from the usual blowholes that are apt to occasion so much difficulty.

Some advantages of electric welding.

Of the different processes above described, viz., the electric welding, electric forging, electric casting, and electric soldering, the former is by far the most valuable. While it is true that electric welding presents many difficulties in actual practice, where a great variety of work is to be accomplished, owing to the fact of the great variations in the current strengths and pressures required, yet where a sufficient number of weldings of the same type and character are required to be done, electric welding possesses very marked advantages over any other method. Some of the more marked advantages possessed by electric welding over ordinary processes are thus referred to in a report made by Silvanus P. Thompson, Professor of Experimental Physics, in the University College, Bristol, England, as follows:

Professor Silvanus P. Thompson on electric welding.

"I have examined not only the welding machines in which the operation is conducted and specimens welded by their use, but also the electric machinery for generating or supplying the electric currents. Every facility has been granted to me for observing the construction and action of the whole of the machinery and for handling it myself. I have made a number of electrical measurements upon the currents supplied by the generators to the welding machines during the execution both of large and small welds, and in particular made a series of electrical

measurements upon the eighty specimen welds executed at Hoxton, in the presence of Sir Frederick Bramwell, at which trial I also was present.

" . . . One of the most striking features of the process is the precision with which the heat is localized at the spot required. For example, when two bars of inch-iron or steel are welded, they become red-hot for a length of about 1½ inches on either side of the weld, but at distances an inch further from the weld are quite cool when they come from the machine. There is, therefore, no unnecessary waste of heat. This arises partly from the excellence of the arrangements for clamping the pieces in massive copper clamps, but it is mainly due to the great rapidity of action inherent in the process. The introduction of the electric transformer enables enormous currents to be so applied to the weld as to spend their energy just at the point where heating is required. They need, therefore, only to be applied for a few seconds, and the operation is completed before the heat generated at the weld has had time to escape by conduction to any other part. The time required, for example, to weld round iron bars of 1⅛-inch diameter was on the average less than 33 seconds; though it could be accelerated to 25 seconds, or lengthened so as to last 45 seconds. Round bars of steel of ¾-inch diameter only required 16 seconds for welding, and were quite cool at a distance of 1¾-inch on either side of the weld.

Time element in electric welding.

"Such rapidity is the consequence of the arrangement which permit an enormous electric current to be suddenly generated exactly at the time and place where the local heating is required.

"Although the quantity of the current so employed in the pieces to be welded is enormous, the potential at which it is applied is extremely low, not much exceeding that of the batteries of cells used for ringing

electric bells in houses, and quite incapable of giving any shock to the operator. While a weld was being made I have grasped the copper clamps of the welding machine with my two hands (having moistened them previously to render the skin more susceptible), but was unable to perceive the smallest shock or other sensation. The primary circuit of the machine is at a higher potential; high enough, if not protected, to give a sensible but not a dangerous shock. This portion of the machine is, however, not accessible from the side where the operator works, and is securely guarded. I have, myself, while standing on the floor, touched all the accessible parts of the machine back and front while it was in action, and have been unable to detect more than the faintest tingling. I consider, therefore, that the machine may be used with entire freedom from risk to life or limb. . . .

Safety of electric welding process.

"I procured from Messrs. Pfeil & Co., of Clerkenwell and Sheffield, some samples of cast-steel of a quality which is largely employed for tool steel. This material is generally regarded as unweldable, and the samples procured by me were found to bear the maker's usual label, stating that 'this steel is not weldable.' These samples I sent to Hoxton, where the engineer in charge of the welding found no difficulty in welding them, the welds proving, when cold, to be good welds, quite satisfactory for the purpose of steel tools.

Satisfactory character of electrically welded joints.

"Some other tests I have made of an electrical nature upon samples of welds produced by the Thomson process. I have measured the electric conductivity of various welded bars with the view of ascertaining whether the conductivity of the welded joint was inferior to that of the rest of the bar. In very few cases was the conductivity of the joint at all lower than that of the rest of the bar; in

most cases it was the same, and in two cases (steel) actually higher. Such tests, in my judgment, go far to show that a very perfect homogeneity of structure is secured by this method of welding. This is what one would expect from a method of welding in which the union of the parts commences at the interior, and works outward until the weld is complete, and in which the surfaces which are to be united are not exposed heated to the air, but are only heated in the act of forcing them into contact with one another."

Perfect homogeneity of structure secured.

VI

ELECTRO-THERAPEUTICS

CHAPTER XXXI

EARLY HISTORY OF ELECTRO-THERAPEUTICS

ELECTRO-THERAPEUTICS, or electro-therapy, is that branch of electric science which treats of the applications of electricity to the curing of disease. It forms a branch of the more general subject of electro-biology, which treats of the electric condition of living animals and plants, and the effects produced in them by electricity. Electro-biology includes two distinct subjects; viz., electro-physiology, which treats of the electric phenomena of animals and plants, and electro-therapeutics. As far as the presence of electric currents in plants and animals is concerned, electro-physiology has already been generally referred to.

Electro-therapeutics and electro-biology.

In our study of electro-therapeutics, we shall be able briefly to discuss only the apparatus required to produce the electric charges and discharges that are employed in the treatment of diseased conditions of the human body, as well as the general phenomena produced in different parts of the body by the application of electricity. This treatment by no means covers the entire subject of electro-therapeutics. In addition, there should be given a thorough knowl-

Wide range of studies required for knowledge of electro-therapeutics.

edge of electricity, together with a limited knowledge of electro-technology. There should also be added a thorough knowledge both of anatomy and physiology; anatomy, as treating in general of the internal structure of the body and its various organs, as revealed by actual dissection, and physiology as embracing the phenomena of life, together with the functions of the different organs of the body. This will include a knowledge of the circulation of the blood, respiration, digestion, absorption, secretion, and excretion, as well as the study of the general and special nervous systems. To anatomy and physiology there should be added a knowledge of pathology, or that branch of medical science which treats of the diseased conditions of the organs of the body, of the symptoms of such diseased conditions, their predisposing and existing causes, together with a knowledge of their progress. Pathology, therefore, embraces diagnosis, or the determination of the character of the disease, and prognosis, or an opinion as to the probable results of the diseased condition. But in addition to these, a complete treatment of electro-therapeutics should include a knowledge of materia medica; *i.e.*, of the pharmaceutical agents employed in the treatment of abnormal conditions of the body, since the best results can only be obtained from the application of electricity when taken in connection with ordinary treatment.

Scope of physiology.

Knowledge that should be possessed by the electro-therapist.

But it would clearly be impossible, in the limits of this book, to enter into a discussion of these various parts of the science, since to do so would practically necessitate a treatise on the medical arts and sciences. We shall, therefore, content ourselves with a discussion rather of electricity in electro-therapeutics than the discussion of electro-therapeutics in its entirety.

It is evident that a very extended knowledge is required on the part of the electro-therapist. In addition to being an adept in electric science, and, to a limited extent, an electro-technologist, he should be a skilled anatomist, physiologist, and pathologist, as well as a pharmaceutist. Moreover, he must have learned how to apply these branches to the every-day practice of his profession. Unfortunately, a general belief exists among a certain class in the community that any one is capable of safely acting as his own doctor, so far as treatment by electricity is concerned. Although it is generally recognized that a necessity exists for limiting ordinary medical treatment to the regularly licensed practicing physician, yet it would appear, by some strange process of reasoning, to be believed that, so far as electrical treatment is concerned, a difference exists. If one can only become the possessor of some form of electrical machine or medical battery, he is too prone to believe himself fully competent to treat either himself or others. This conclusion is probably based on a process of reasoning not unlike that which induces the medical charlatan to write the old shotgun prescription, which contains, perhaps, some dozen or more drugs, in the vain hope that some of them may chance to be the required remedy.

The dangers arising from the unscientific employment of electricity.

Shot-gun prescription of old medical schools.

It is exceedingly difficult to pass an electric discharge through a limited part of the body. In practically all cases, some of the current passes through all the remaining parts of the body. The general belief appears to be that, no matter how or where applied, the diseased portion of the body must necessarily be reached. It needs no philosopher to see that, as with the shotgun prescription, the little good which might possibly result should the prescription contain, by chance, some one or more of the re-

quired remedies, might be more than balanced by the evil effects of some of the remaining remedies. So, too, in the similar treatment of the human body by electricity, the good that may be done in one direction is often more than negatived by the evil done in other directions.

Unquestioned good effect of electro-therapeutic treatment.

There can no longer be any doubt that electricity, when properly applied to a diseased body, is capable, in many cases, of restoring it to its normal condition. This it does in various ways, either by stimulating different organs or functions of the body, by reason of its action on the nerves and muscles, or by restoring the secretions and excretions to their normal activity. But there can equally be no doubt that, in the hands of an ignorant person, electricity is capable of doing far more harm than good. How can one intelligently apply a powerful curative remedy like electricity, unless he is able to determine whether the patient needs such treatment, whether, in reality, any diseased condition exists; and, supposing that it does exist, how can such a person determine when the proper time has come to stop the treatment, by reason of the diseased condition having been overcome or cured? To do either of these things intelligently, he must be equally able to recognize with certainty the characteristics of disease and health. As is well known, in certain diseased conditions, increased stimulation of any of the functions of the body may result fatally, while, in other conditions, a failure to stimulate certain functions may result in death. Clearly, for an ignorant person to apply indiscriminately to the entire body a remedy that may increase the stimulation of certain parts, or decrease the stimulation of others, is both foolish and dangerous.

Electric charlatans.

In all intelligent governments, the general public is protected from the danger arising from improper medical treatment by legal enactments that forbid, under heavy penalties, the practicing of medicine except by those who can show diplomas received from regularly authorized medical schools. Such protection is even more required in the case of electro-therapeutical practitioners, and, fortunately, in some parts of the country, this protection has been partially afforded. But what would appear to be equally needed, is the protection of people against themselves; and this can only be effected by a general discrimination of the facts of the case. It is sometimes urged against those who would obtain the enactment of a law limiting the practice of medicine or electro-therapeutics to those who have been regularly instructed in the art, based on actual experience, that, in no inconsiderable number of cases, people that have never possessed the advantages of such training, can undoubtedly produce abundant evidence of their having obtained marked cures. It should not be forgotten, however, even assuming such certificates of cure to be reliable, that it is only the people who are cured that write the certificates, not those who are killed. Probably, one of the best ways of protecting the public in this direction would be the enactment of a law which would impose heavy penalties on all who advertise the cures which they claim they have brought about, unless, at the same time, a publication be made containing a true statement of all the cases that they have actually treated, together with the results of such treatment.

Regularly licensed electro-therapeutic practitioners desirable.

From the earliest times, even, indeed, up to to-day, men appear to be willing to try any remedy, however strange it may be, in order to regain their health.

The stranger, the more popular the remedy.

Indeed, the stranger or more mysterious the remedy, the more willing and desirous they appear, in many cases, to try it.

If we may credit the statement of a Roman writer, one Scribonius Largus, as early as 50 A.D. a Roman freedman named Anthero subjected his body to a number of shocks from an electric torpedo in order that he might be cured from a troublesome attack of gout.

Scribonius Largus and the gout.

It is an exceedingly interesting fact that in nearly all cases the discovery of a new electric source has been followed by its almost immediate application to the curing of diseased conditions of the human body. The early frictional electric machines were employed for the curing of diseases in a manner that was very similar to that in which they are employed to-day, although of course their use then could not have been as intelligent as it may be to-day. Cavallo, in his book on Electricity, already referred to, states that in 1748 Jellabert, of Geneva, subjected a number of invalids to the action of the discharge of a frictional electric machine in practically the same manner as such a machine is employed to-day; viz., by connecting one of the terminals to the body of the patient to be treated, and taking either disruptive or convective discharges from various parts of the body by a blunt and polished metallic ball or metallic points or combs connected with the other terminal of the machine. Cavallo claims that in this manner Jellabert had been able to cure one of his patients whose right arm had been paralyzed. Manduyt, too, in 1871, claims to have similarly cured one of his patients who was suffering from paralysis.

Cavallo and electro-therapeutics.

The Leyden jar and electro-therapeutics.

The invention of the Leyden jar, in 1745, was immediately followed by its application to curative purposes. The strange and astounding physical effects produced on the human body by its discharge led to the most extravagant ideas concerning its therapeutic power, and it was employed to a considerable extent for the curing of diseases. There is very little doubt that such use is attended in some cases by satisfactory results, for, as we now know, such discharges, when properly applied, are often attended by a marked improvement in the condition of the patient.

Humboldt and Aldini on electricity as a curative agent.

The invention of the voltaic battery was almost immediately followed by its application as a therapeutic agent. One of the earliest workers in this direction was Humboldt, who made a series of investigations on the effects produced on the human body by the discharge of the voltaic battery. Another early writer on this subject was Aldini, a nephew of Galvani, who published a book on the electric curing of diseases.

The induction coil in electro-therapy.

The invention of the induction coil was another instance of an electric source that was no sooner invented than it was applied as an electro-therapeutic agent. This use has extended down to the present day, this form of electric apparatus being very frequently employed for the curing of disease.

It is a strange fact that many of the early electro-therapeutists believed that the curative properties of medicinal substances contained in sealed glass vessels could readily pass through the walls of the vessel and so act on persons placed near them. Probably this was due to the fact that at this time there existed a general belief in what were called effluvia,

that is, matter in a state of very fine division. We find in the early electric literature a statement made by Dr. Bruni to Franklin that medicine shut up in sealed glass vessels produced their characteristic effects on a person who was electrified by the use of such vessels.

Bruni on medicated electric tubes.

It will be interesting to note what Franklin said concerning Dr. Bruni's communication. The following extract is taken from remarks made by Franklin before the Royal Society:

Franklin's communication to the Royal Society.

"Dr. Bruni gives me next in his information from Rome, which is, that a gentleman there covered the internal surface of a glass cylinder (which some use instead of a globe) with a purgative medicine; and that a man, electrified therewith, found on the spot the same effect as if he had swallowed the medicine. He then recommended to us, in England, to try how far the electric power may be of service in distempers.

"These cases, and particularly the last, as it may to some appear extravagant and whimsical, I should have been cautious of bringing before the Royal Society, had you not judged it proper they should be added to those similar accounts from other places, which were read to us last meeting. I think neither myself nor Dr. Bruni answerable for the truth of these facts, as we relate no more than we have received. In truth, all the phenomena in electricity are so wonderful that it is scarcely prudent to deny the possibilities of any accounts concerning it till we have made experiments carefully ourselves. We are very sure it is possible to render a living body replete with electrical effluvia, or to transmit and send such effluvia through a living body, in a stream, as long as we think proper: we are not sure that it is impossible for these effluvia to convey with

Franklin's belief as to the danger of too hurriedly denying electrical possibilities.

them into that living body the most subtile and active effluvia of other substances; and if they can do so, the effects suggested are not wholly improbable, for several experiments have proved that a very minute quantity of medicine, transfused directly into the blood and circulating fluids, will have the same effect as a large dose thereof taken into the stomach."

Alleged transmission of aromatic substances through glass tubes.

In a similar manner, it was believed that various aromatic substances, when shut up in hermetically sealed glass vessels, were able to be transmitted through the walls of such vessels to such an extent that they could readily exert their peculiar influence on the bodies of persons placed near the vessel.

Notwithstanding the recent strange results obtained by the use of the radium rays, which, as we know, possess the power of penetrating many solid substances, there can be but little doubt that the preceding ideas had no foundation in fact.

CHAPTER XXXII

ELECTRO-THERAPEUTIC APPARATUS AND TREATMENT

THE principal electric sources that are employed in electro-therapeutics have, for the greater part, been already referred to in the preceding volumes of this work. Generally, however, some slight modifications are given to such apparatus when employed by the electro-therapist. The underlying principles of their operation are of course the same, no matter for what purpose they may be employed.

Electric sources employed in electro-therapeutics.

Electro-therapeutic apparatus consists broadly of various electric sources and of different electro-receptive devices that are employed for the purpose of obtaining some of the many effects electric currents are capable of producing. Some of the principal electric sources are the frictional electric machine, the electro-static induction machine, either with or without Leyden-jar batteries, various forms of voltaic batteries, dynamo-electric machines or generators, together with different forms of induction coils and alternating-current transformers.

Some electro-therapeutic sources.

The above-named sources are employed either for the purpose of transmitting the electric currents so produced directly to the body of the patient, or for use in connection with other apparatus for the pur-

Some uses of electric sources.

pose of obtaining the desired heating, magnetic, electrolytic, and luminous, or other radiation effects that are desired.

Electro-static induction machines.

The old forms of frictional electric machines, although at one time very generally employed in electro-therapeutics, are now almost entirely replaced by some of the forms of electro-static induction machines already described. For electro-therapeutic apparatus electro-static induction machines may be employed with from 2 to 16 plates. In these machines half the plates are fixed and the other half are capable of being revolved.

FIG 263.—Wagner 16-plate Electro-static Machine.

Wagner 16-plate electro-static machine.

In the case of the machine represented in Fig. 263; *i.e.*, a 16-plate Wagner electro-static machine that is considerably employed in electro-therapeutics, 8 of the plates are fixed and the remaining 8 are capable of being revolved. Here the plates are com-

posed of a composition of thin films of mica and shellac that is formed as follows: Sheets of mica that are separated from one another in as thin films as possible are placed inside a steel form with layers of finely divided shellac placed between them. The form is heated so as to soften the shellac, and is then subjected to heavy hydraulic pressure. In this way plates are obtained that can be readily run at some 2,000 revolutions per minute without danger of breaking. Composite mica plates formed in this manner also possess the advantage of not being so readily affected by deposits of moisture from the atmosphere as are glass plates. In order, however, that the apparatus shall be kept as free as possible from moisture deposited on it from the atmosphere, it is covered by a glass case, inside of which is placed some substance like calcium chloride, that possesses a strong attraction for moisture. The machine is generally arranged so as to be set into revolution by an electric motor or by a water motor. Leyden jars are placed so that they can be connected with the sliding metallic terminals, and thus permit either the condensed spark or the convective discharge to be obtained. This latter discharge is generally known in electro-therapeutics by the questionable name "static breeze."

Method of manufacturing mica-plates for electro-static machines.

The so-called static breeze.

In the employment of an electro-static machine, the patient is generally placed on an insulated stool on a metallic plate that covers a part of its upper surface. One of the terminals of the machine is connected with this plate, and the other is held in the hand of the operator by means of an insulated handle. This terminal of the machine is either provided with a polished metallic ball that is brought near to different portions of the body of the patient from which it is desired to take electric sparks, or

Method of applying electric currents of electro-static machines for electro-therapeutic purposes.

it is connected with a metallic point when it is desired to draw the convective discharge from the different parts of the body of the patient to which it is approached.

Ozone and ozone generators.

As is well known, during the discharge of powerful electric machines a considerable quantity of ozone is generated. In some cases this ozone probably forms an important part of the electro-therapeutic value of electricity applied in this manner. It is sometimes concentrated, however, in devices called ozone generators, which operate practically by the discharge of the electric spark through a confined mass of air, which is afterward blown on an exposed portion of the body of the patient who is being treated.

Silver-chloride battery for electro-therapeutical purposes.

Voltaic batteries are employed to a great extent in electro-therapeutics. These batteries generally consist of series-connected batteries of different forms of voltaic cells. The silver chloride voltaic cell is suitable for all purposes where a small current of high electro-motive force is desired. This cell consists of a zinc-silver couple immersed in electrolytes of fused silver chloride and sal ammoniac. Each cell gives an electro-motive force of 1.03 volts. Fig. 264 shows a voltaic battery of this type with 50 separate cells that can be connected in series. They are arranged, however, so that all or a part of the cells can be employed at one time.

Some other forms of voltaic batteries.

Where more powerful electric currents are necessary, batteries of the silver chloride type would be impracticable. In such cases the battery is formed of other types of voltaic cells or by combinations of storage cells. Voltaic batteries of this latter type are generally employed where the heating effect of

the current is required, or, as it is called, for cautery effects.

Employment of electric storage cells for electro-therapeutic batteries for cauteries, etc.

Where batteries are employed consisting of a number of series-connected storage cells for cautery purposes, as well as, indeed, for any purpose requiring a large amount, there is provided in the apparatus a number of separate resistances that can be readily introduced into or removed from the circuit connected with the battery by means of a suitable form of rheostat or regulable resistance box. Fig. 265

FIG. 264.—Battery of Fifty Series-Connected Chloride of Silver Voltaic Cells. Note the series connections of the separate voltaic cells. These connections are generally so made that various electro-motive forces are readily obtained by employing all or only a portion of the cells at one time.

represents a form of storage battery of this type. The current is taken from the binding posts represented at A and B, and the regulable switch arm S is so arranged that it is capable of moving so as to introduce into or remove from the circuit any or all of the resistances. In this manner the strength of the current produced is readily regulated within certain limits.

Dynamo and magneto-electric machines.

Various forms of dynamo-electric machines and magneto-electric machines are employed for generat-

ing the currents employed in electro-therapeutics. These machines are either driven by the hand or by means of electric motors.

Induction or Faradic coil.

The induction coil, or, as it is more frequently called, the Faradic coil, is very generally employed in electro-therapeutics. The medical induction coil is most generally employed in the form of a step-up transformer, though sometimes it is employed as a step-down transformer. The currents that are

FIG. 265.—Portable Cautery Battery (Storage Cell Type). Note the simple manner in which various resistances are introduced into, or removed from, the circuit.

passed through the primary circuit are generally obtained from a suitably connected voltaic battery, the secondary of the coil being connected either directly to the electrodes applied to the body of the patient or to the apparatus that is used in connection with such electro-therapeutic treatment.

In order to obtain the necessary alternations or makes and breaks of the current some form of

automatic make-and-break apparatus is employed. Sometimes induction coils are operated by means of alternating currents obtained from a motor-driven dynamo. In this case true alternating currents are employed.

Automatic make-and-break apparatus.

The electric currents produced by induction coils are sometimes called Faradic currents in order to distinguish them from the currents produced by the voltaic batteries, that are called Galvanic currents. In a similar manner currents produced by electro-static induction machines, or frictional machines, are sometimes called Franklinic currents.

Faradic, Galvanic, and Franklinic circuits.

Sometimes portable apparatus is constructed that is capable of producing either Faradic or Galvanic currents. In this case the instrument contains both a voltaic battery and an induction coil. Such an instrument is represented in Fig. 266. The entire apparatus is placed inside a portable box, which is furnished with terminals so that either the Faradic or the Galvanic current may be applied to the body of the patient.

Combined Faradic and Galvanic apparatus.

A form of alternating-current transformer is employed in electro-therapeutics in which either the primary or the secondary circuit may be applied to the patient, so that either small currents of high electro-motive force or large currents of small electro-motive force may be obtained. The coils consist of insulated copper wire so proportioned as to be suitable for direct connection with an incandescent electric lamp circuit having a pressure of from 52 to 104 volts. By this means high electro-motive forces and small currents are obtained similar to those produced by the secondary circuit of the ordinary medical induction coil, or low electro-motive

Alternating-current transformer for electro-therapeutics.

forces and powerful currents are obtained that are necessary for cautery purposes. An electric current transformer of this character is represented in Fig. 267.

The passage of an electric current through the human body produces four different classes of ef-

Fig. 266.—Combined Galvanic and Faradic Portable Battery. Note here a form of galvanometer, called a milliampèremeter, employed for the purpose of giving the current strength in milliampères or the thousandths of an ampère. The induction coil is represented on the right, and the switch of the rheostat between the induction coil and the milliampèremeter.

Different effects produced by passage of electric discharge through the human body.

fects; viz., magnetic, electrolytic, osmotic, and cataphoric. The first two classes of effects are of but little importance from an electro-therapeutical standpoint. The remaining two are of considerable importance.

It is now well known that when an electric current produces electrolytic effects, as are produced in

decomposition of various liquid solutions or conductors, although the products of decomposition appear only at the electrodes, yet there is produced throughout the entire mass of the electrolyte between the electrodes or poles a movement of separate portions or ions that is generally called the migration of the ions. In this case the positive ions move throughout the mass of the liquid in a positive stream toward the negative pole, while the negative ions move in the opposite direction toward the positive pole. It is evident, therefore, that when an electric current is passed by means of suitable electrodes

Ionic streams produced in electrolyte during the passage of an electric current.

Migration of the ions.

FIG. 267.—Alternating-Current Transformer for Therapeutic Purposes. The current to be transformed is obtained from a 52 or 104-volt alternating-current incandescent lamp circuit.

through different portions of the human body, the electro-motive force being sufficiently high to produce electrolytic decomposition, marked effects may be produced by the movements of the ions throughout all those portions that lie between the electrodes, as well as those which may be produced by the electrolytic decomposition of portions of such fluids.

Moreover, since in electrolytic decomposition of the human body there is produced an actual movement of the ions from the positive to the negative electrode, it should be possible to transmit medicinal substances from the outside of the body to different

Cataphoresis and cataphoretic medication.

parts of the interior, and in this way to obtain the therapeutic effects of such remedies by actually applying them directly to the parts that require treatment. The application of medicinal remedies in this manner is called cataphoretic medication, and the process itself is called cataphoresis. Cataphoretic medication is extensively employed at the present time in electro-therapeutics.

Manner of applying cataphoretic medication.

In cataphoretic medication the substances that are to be applied to some interior parts of the human body are placed in a solution on the surface of an absorbing material that covers the positive electrode, this electrode being placed in such a position as will most readily cause the current to pass through the parts that are to be treated. The current is turned on and its passage through the portions of the body between the two electrodes carries some of the medicinal remedy to the portions of the body that are to be treated.

Engorgement and depletion of internal human organs produced by the passage of an electric current.

The passage of an electric current through the human body, even when direct cataphoretic medication is not employed, must necessarily be attended by an engorgement of certain portions of the body and a depletion of some of its fluid substances in other parts, since the movement of the current is attended by a bodily movement of the liquid itself. In this way, then, an electric current may produce either beneficial or injurious effects on the portions of the body through which it is passed, according to whether the organs that are engorged by its passage previously contain a surplus or deficit of its liquid contents.

So far as the production of magnetism by the electric current is concerned, it does not appear that

magnetism is able to produce any positive effects on the human body. Although experiments have been made in which the most powerful magnetic flux has not only been passed through the human body, but has even been condensed on such delicate portions as the brain, no observable effects were produced.

Magnetism apparently produces no effects on human body.

The electric current is applied to various parts of the body in electro-therapeutical treatment by means of terminals or electrodes, that consist of various polished metallic bodies shaped either so as to be readily applied at different portions of the body, or as to be readily introduced into its various cavities. Sometimes the surfaces of the metallic electrodes are covered with chamois leather or cotton or linen fabrics, that are then moistened with salt water in order to ensure a better contact between the electrodes and the external skin, which in itself possesses high electric resistance. Sometimes moistened sponges are employed for the same purpose. Even moistened masses of clay have been similarly employed.

Various kinds of electro-therapeutic electrodes.

The ability of an electric current to heat metallic wires to incandescence has led to the general use of the electric cautery for the various purposes that require an incandescent knife or cutting instrument. Such methods are employed for the removal of diseased growths from various parts of the body. In some cases the knives consist of short pieces of platinum wire that are placed around the diseased portion that is to be removed, and when heated to incandescence are drawn tightly together, thus cutting through the diseased part. Various forms are given to electric cautery knives, some of which are represented in Fig. 268.

Electric cautery electrodes.

Use of electric incandescent lamp for exploration of human body.

The ease with which small electric currents produce a fairly considerable amount of light by the incandescence of carbon filaments has led to a very general application of such sources of incandescence for the examination of diseased portions of the human body. A great variety of apparatus has been produced for the illumination of the various cavities of the body, such, for example, as the

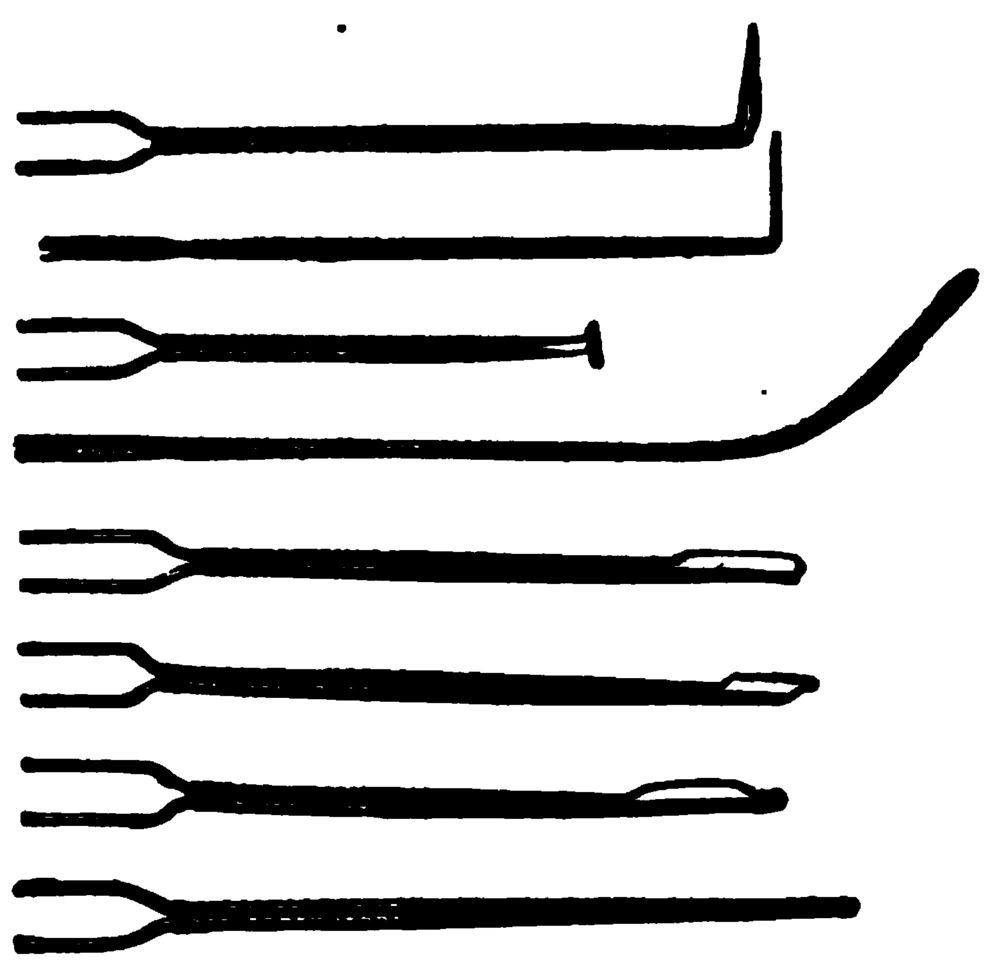


FIG. 268.—Various Forms of Galvano Cautery Electrodes. Note the different forms assumed by these electrode knives.

mouth, throat, nostrils, stomach, bladder, uterus, etc. This is effected by the introduction of miniature electric lamps into the different cavities. In some cases the light is concentrated by the use of reflectors. Sometimes more powerful electric lights are employed outside the body for throwing the light after its reflection from suitably supported mirrors. A form frequently employed for this purpose consists of an incandescent lamp placed at

the focus of a mirror and supported on the head of the doctor by a suitable band.

Use of X-Rays in exploring interior of human body.

Reference has already been made to the use of the X-rays for the purpose of locating the position of foreign metallic substances in various parts of the human body, and to the ease with which photographs can be taken that will not only show the position of such foreign bodies, but will also give some idea of the conditions of the internal organs themselves.

CHAPTER XXXIII

ELECTRIC MEASURING INSTRUMENTS

IN order to determine the current that is passing in any electric circuit it is only necessary to know two of the three following qualities; viz., the electric resistance, the electric current, and the electro-motive force, since, according to Ohm's

Ohm's Law

Law $C=\frac{E}{R}$ will give by simple methods the remaining quantity; for example, the current is equal to the electro-motive force divided by the resistance; the electro-motive force is equal to the product of the current and the resistance; while the resistance is equal to the electro-motive force divided by the current strength.

Ampères, volts, and ohms.

There are many ways in which the three quantities may be determined. In this determination it is sometimes necessary to note the capacity of the circuit expressed in units of capacity called farads or microfarads.

Farads and micro-farads.

It will be impossible on account of the limited space to give anything more than a very general account of some of the methods by which these different quantities may be readily determined.

Remembering that Ohm's Law may be written

$$\text{Ampères}=\frac{\text{Volts.}}{\text{Ohms,}}$$

let us very briefly consider some of the ways in

which the ampères, the volts, and the ohms may be determined in any circuit. This can be done readily by the use of apparatus which will give one of these values directly.

Galvanometers. **Ampèremeters or ammeters.** The ampères may generally be determined by the use of some form of galvanometer. That in which the current strength is given directly is called the ampèremeter or ammeter. When graduated so as to give results in milliampères or in thousandths of an ampère, the instrument is called a milliam-

Fig. 269.—Milliampèremeter Suitable for Electro-Therapeutical Work.

Milliampèremeter for electro-therapeutical work. pèremeter. Various forms are given to these instruments. A form of milliampèremeter suitable for electro-therapeutical work is represented in Fig. 269. A pointer or needle connected with a magnetic needle, not shown in the figure, is mounted on a hard steel point that is supported on a polished agate centre. The face of the instrument is marked so as to give directly the current strength passing in milliampères.

The ammeters employed at central stations, where the currents to be measured are necessarily large,

Various types of ammeters.

consist often of only a single turn or coil of insulated wire, or sometimes of even but a part of a single turn or coil, within which a balanced core or magnetic needle is placed, that is capable of freely moving under the influence of the magnetic field produced by the passage of the current through the turn or part of a turn of wire. Where the ammeters are employed for measuring small currents of high electro-motive force, the deflecting coils of wire consist of many thousands of turns of fine wire.

Use of voltameters for determination of current strength.

In some cases the strength of an electric current is measured by means of the amount of chemical decomposition it is capable of effecting. Instruments of this character are called voltameters. An example of a voltameter is seen in the case of the Edison chemical meter, where the current strength passing is measured by the decomposition of a solution of zinc sulphate. Here the value of the current is determined by the increase in the weight of a zinc plate connected with one of the terminals, the other plate suffering a corresponding loss of weight.

Determination of E.M.F. of source by voltmeters

The electro-motive force or difference of potential of an electric circuit may be determined by means of an instrument called the voltmeter. Its construction and operation closely resemble that of the ammeter. As a rule, however, the coils of the voltmeter possess a greater resistance, and are placed in a shunt circuit around the circuit whose difference of potential is to be measured. The voltmeter operates on the principle that the electro-motive force of any circuit is equal to the product of its current strength and the resistance. In its general appearance the voltmeter greatly resembles the ammeter.

The electro-motive force of a circuit is also determined by means of an instrument called the potentiometer, in which the difference of potential to be measured is opposed by a known difference of potential, and the equality or balance is obtained by the failure of one or more galvanometers placed in a shunt to show movements of their needles. Potentiometers.

The resistance of a circuit may be determined in various ways. The instrument most frequently em-

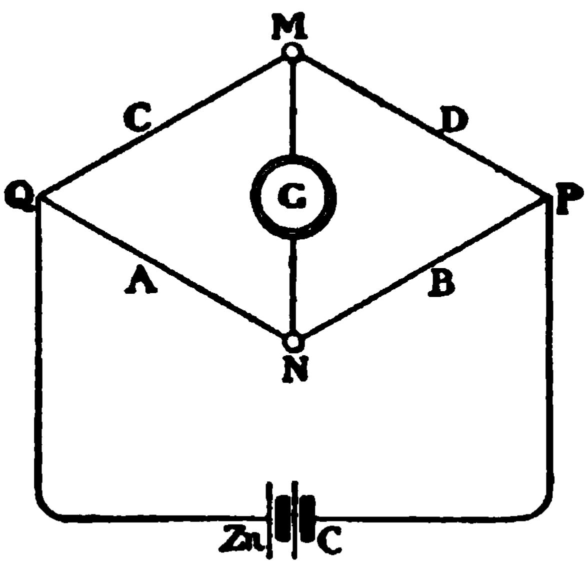


FIG. 270.—The Electric Balance or Bridge. Here the values of the resistances of B and A are made some simple ratio, such as 1 to 2. The unknown resistance is introduced at B, and the value of the resistance D is changed until no current passes through the galvanometer G. The value of B can then be readily calculated.

ployed for this purpose, however, is called Wheatstone's balance or bridge. Its general appearance is represented in Fig. 270, where a voltaic battery, Zn C, is connected as shown to the points Q and P, of a circuit that consists of conductors C, D, A, and B. Between two points of this circuit, M and N, a sensitive galvanometer, G, is placed. The portions of the circuit A, B, C, and D, consist of four electric resistances. Provided the values of any three of these resistances are known, the value of the remaining resistance can be readily calculated. Wheatstone's electric bridge or balance.

Operation of electric bridge or balance.

The operation of the electric bridge or balance is dependent on the following principles: The passage of an electric current through any circuit is attended by a fall of potential on that circuit that is proportional to its resistance. Consequently, if the resistances A, C, and D are so proportioned to the value of an unknown resistance B, that the fall of potential is such that no current passes through the galvanometer G, placed as shown, then it can be demonstrated that the resistance A is to the resistance B as the resistance C is to the resistance D; or, in other words, that the value of the resistance B is equal to the value of the resistance A, multiplied by the resistance D, divided by the resistance C.

Form of Wheatstone electric bridge or balance.

Various forms are given to the electric balance or bridge. In the form represented in Fig. 270, the resistances C, D, and A are formed of resistance coils of known values. These coils are capable of being connected together by the introduction of plug keys in openings that are formed by closely approached plates of metal connected with the free ends of the coils as shown in the figure. Here the resistances or arms A and C consist of resistances marked 10, 100, and 1,000, placed on both sides of Q, while the resistance of the arm D, which forms what is called a resistance box, is represented by resistances numbered from 1 to 5,000. In order to prevent the passage of an electric current through the coils of wire that constitute the various resistances from producing a magnetic field that might seriously affect the needle of the galvanometer placed near or in the resistance box, the wire is first bent on itself, and then wrapped in the shape of a coil. In this case any magnetic flux that is produced by one-half of the coil will be neutralized by the oppo-

Method of winding resistance coil.

site magnetic flux produced by the remaining half of the coil. At the same time, however, the electric resistance which the wire offers to the passage of the current will not be affected.

The capacity of a circuit in microfarads or thousandths of a farad may be determined by means of an instrument called the condenser, the construction of which has already been described in another volume. Use of condenser.

INDEX

D

J

K

L

Q

R

U

V

END OF VOLUME THREE